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**Soil Quality: Marginal Valuation and Socio-Economic Factors Influencing its Level
in the Lowlands of Lesotho, Africa**

by

Derek Parker



A thesis submitted to the Faculty of Graduate Studies and Research in partial fulfilment of
the requirement for the degree of Master of Science.

in

Agricultural Economics

Department of Rural Economy

Edmonton, Alberta

Spring 1995



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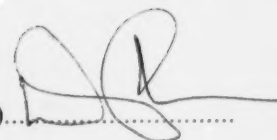
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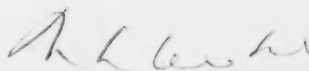
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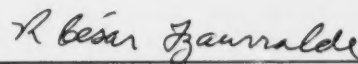
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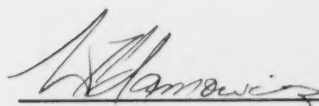
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M. L. Lerohl, Supervisor



R.C. Izaurralde, Committee Member



Wiktor L. Adamowicz, Committee Member

Date December 5, 1994

ABSTRACT

The primary purpose of this study is to establish a marginal valuation of soil quality for the lowlands of Lesotho, Africa. A secondary objective is to assess the relationship between soil quality and socio-economic factors.

Production and econometric analysis are applied to estimate a production function. Explanatory variables include labour availability, farm capitalization, fertilizer application, field slope, and soil quality; the dependent variable is the money value of output per hectare. Soil quality is a composite variable encompassing soil depth, phosphorus and potassium concentration, organic matter content, and pH level. From six soil quality variables, one is selected for inclusion in the production model. A marginal value of soil quality is subsequently determined.

Factors that are hypothesized to influence soil quality – labour availability, conservation effort, socio-political status, farm management variables, and concern for erosion – are addressed using cross-tabulation analysis.

The extra value of crop production attributable to a one unit increase in soil quality is determined. It is proposed that the changes in soil quality arising from conservation effort or degradation processes could be economically measured using such an approach. Of the socio-economic variables proposed to influence soil quality, none were significant at the 0.05 level. The linkage between soil quality and socio-economic factors may be more apparent where a time series data base is applied.

DEDICATED TO MORATUOA,
TEBELLO, AND MAXIME

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CHAPTER ONE

INTRODUCTION

1.1. GEOGRAPHY AND HISTORY OF LESOTHO

Lesotho, a mountainous nation of 1.8 million people situated within the boundaries of the Republic of South Africa, spans only 30,350 square kilometers. The population is growing at an annual rate of 2.63%. One-quarter of Lesotho is composed of lowlands ranging from 1,524 to 1,829 meters; the remainder of the country is composed primarily of mountains rising to a maximum elevation of 3,482 meters. Rains fall in this semi-arid, virtually treeless nation from October to April, however droughts are not uncommon. Mean high temperatures during the rainy season generally range in the mid-twenties (centigrade); the vast majority of recorded frosts in the more populated parts of Lesotho occur from May through to August.

The origination of Lesotho dates back to 1500 AD when different ethnic Bantu groups began residing between the Vaal and Caledon rivers. Within two hundred years, the San, or Bushmen, a hunter-gathering society which had lived in the area for thousands of years prior, was displaced and assimilated into the emerging Bantu population and culture. Fruitful years of the formation of a distinct Basotho (pronounced Ba-su:-tu:) nation – when livestock numbers were increasing and sorghum crops were grown in fertile valleys – were almost laid to waste by Zulu attackers from the east in the early 1820's and by clashes with the expanding territorial

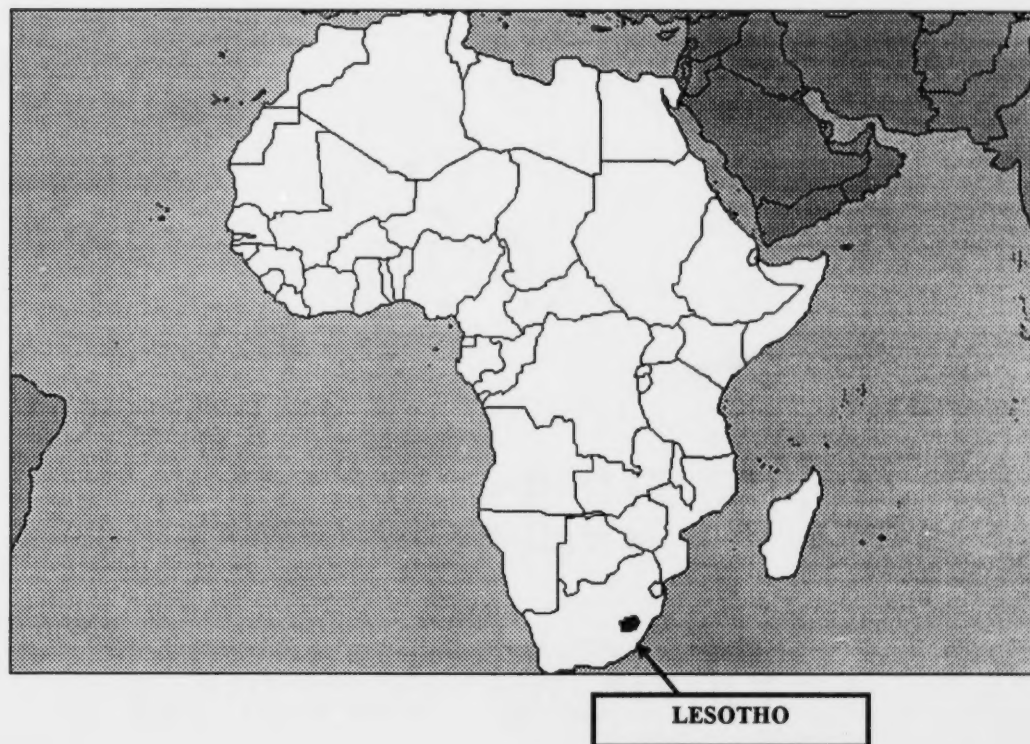
claims of the white Afrikaner farming community. Years of battle reduced the nation to scattered groups struggling for survival. In 1824, a chief and his followers, established camp on a mountain top – a natural fortification against attackers – where, after six years of intelligent diplomacy and warfare, Chief Moshoeshoe emerged as the most eminent leader of the Basotho nation. Continuing battles with Afrikaner settlers led to the establishment of a de facto border in 1866 whereby much Basotho dominated territory was lost to the Orange Free State. In 1868, with British uneasiness about the relentless pursuit of territory by the Dutch-descendant Afrikaners, a proclamation was drafted declaring that “the tribe of the Basutos (sic) shall be, and shall be taken to be, British subjects; and the territory of the said tribe shall be, and shall be taken to be, British Territory.”¹ This arrangement was maintained up to 1966 when independence was granted and Basutoland took on the title Lesotho. Although Lesotho was originally an assemblage of regional tribes, it has become unified in culture and language: while 85% speak Sesotho (15% Zulu), 99% are considered ethnically Basotho.

In the mid 1800's, contact with white settlers brought new crops such as maize, wheat, potatoes and peaches to Lesotho along with the plough. Missionaries in 1874 described Lesotho as a land of plenty with surplus agricultural production recorded up to the late 1920's. The discovery of diamonds (1867) and gold (1884) in South Africa initially fuelled demand for agricultural output from Lesotho so much that a tariff was placed on grains entering the Orange Free State from Basutoland in 1887. Advances in agriculture, continuous cultivation, intensified livestock grazing,

¹ Austin Coates (1966) quoting British colonial documents.

and increased demands for firewood, however, increased pressure on the fragile soils of Lesotho. Initial signs of the vulnerability of pastures and cropland to erosion was evident to foreign missionaries as early as 1833.

Figure 1.1. Lesotho's Place in Africa (© 1992 PC Globe, Inc.)



1.2. LAND DEGRADATION AND CONSERVATION IN LESOTHO: A BRIEF SKETCH

A far reaching effort to stem the rates of land degradation was undertaken in the mid 1930's by the British colonial government when erosion was identified as a key constraint to the socio-economic development of Lesotho (Pim, 1935). The problem remained unresolved when independence was achieved, prompting the involvement of the new government and a number of non-governmental organizations (NGO's).

Since 1935 more has been spent on soil and water conservation than any other agricultural-related activity (Nobe and Seckler, 1979). Losses in agricultural productivity, generally attributed to the effect of farming practices and their impacts on erosion and fertility, have been documented. Although some farmers do employ conservation techniques (terracing, digging diversion ditches, planting trees and grasses and so forth), it is generally asserted that their numbers are too few (Blaikie, 1985).

1.3. AGRICULTURE AND ECONOMY

Primary agricultural outputs in Lesotho include maize, sorghum, melons and wheat. In 1989, some 186,000 hectares, or 62% of total cultivated land, was devoted to maize production. An average of 737 kg of maize grain per hectare was produced in the same year. Sorghum accounted for 18% of total cultivated cropland in 1989 (Lesotho Bureau of Statistics, 1990). Production of asparagus, wool and mohair are less significant in the domestic market yet provide Lesotho with much needed foreign currency.

Livestock bears significantly on Basotho social culture and agriculture. In 1973/74, the estimated head of cattle numbered 465,500 increasing to 627,270 by 1987/88. A high level of cattle imports between 1976 and 1980 coincided with an increase in the number of Basotho working in South African mines and a concurrent increase in mining wages (Lesotho Agricultural Situation Report, 1990). The number of sheep increased less dramatically: from 1.6 million in 1973/74 to 1.7 million in

1986/87. The number of goats increased from 1 to 1.1 million over the same time intervals (Lesotho Agricultural Situation Report, 1990). Livestock grazing is controlled on a communal basis dictated by the local chief; grazing typically takes place at higher elevations in summer or cropping months, and in lower regions during winter months.

Lesotho's domestic economy is weak relative to neighboring South Africa which it is dependent upon for the import of items such as manufactured goods, clothing, foodstuffs, livestock, cereals, building materials, and vehicles. In 1989, despite of the exportation of some diamonds, wool, mohair, and foodstuffs, Lesotho maintained a balance of trade deficit totalling over one-half billion Canadian dollars.

Rural Basotho, representing 81% of the total population, rely heavily on cash remittances from migrant miners in South Africa as a source of household income. 59.3% of rural households depended on these remittances as their primary source of income in 1986. Those relying primarily on subsistence and cash cropping accounted for 24.8% of the population.

Political changes and recessionary forces in South Africa have rendered many Basotho miners jobless. Urban swelling and an increased reliance on farm income may result, but with less than 12% of the land considered arable, pressure on land resources are not likely to be relaxed. Furthermore, the rural environment is unusually prone to erosion due to subsoil formations, steep inclines, and overgrazing among other causes. It is estimated that 25% of arable land is so highly eroded that it cannot be farmed (Schmitz and Rooyani, 1987).

1.4. OBJECTIVES

The goal of this study is to outline and investigate the linkage between soil quality, land conservation, and agricultural productivity. The objectives of the empirical analysis presented in chapter four are twofold. First, a number of different soil quality measurements are applied within four production functions through econometric analysis to establish the most appropriate soil quality variable and functional form. The marginal physical product of soil quality, which provides a means of assessing the economic value of positive and negative changes in soil quality, can then be assessed. The second objective of the empirical work is to apply a choice soil quality variable in a study of potential socio-economic determinants of soil quality.

Through the empirical analysis contained in chapter four, an acceptable soil quality variable is established and applied within a Cobb-Douglas production function (the best-fitting functional form) where fixed farm capital, fertilizer application, and field slope compose the other key production variables. An estimated marginal value of soil quality is subsequently established. It is revealed that establishing socio-economic determinants of soil quality is not feasible in this study, possibly due to data specification or collection errors, or the cross-sectional nature of data the analysis draws upon.

The work contained within and underlying this thesis was directed towards establishing a methodology for delineating and valuing soil quality. Conservation based projects or activities could derive valuable information by monitoring changes in soil quality, and doubly so by the provision of a means or procedure to estimate the

economic value arising from their efforts. Conversely, the economic loss associated with land degradation is also addressed through a study of this nature.

1.5. METHODOLOGY

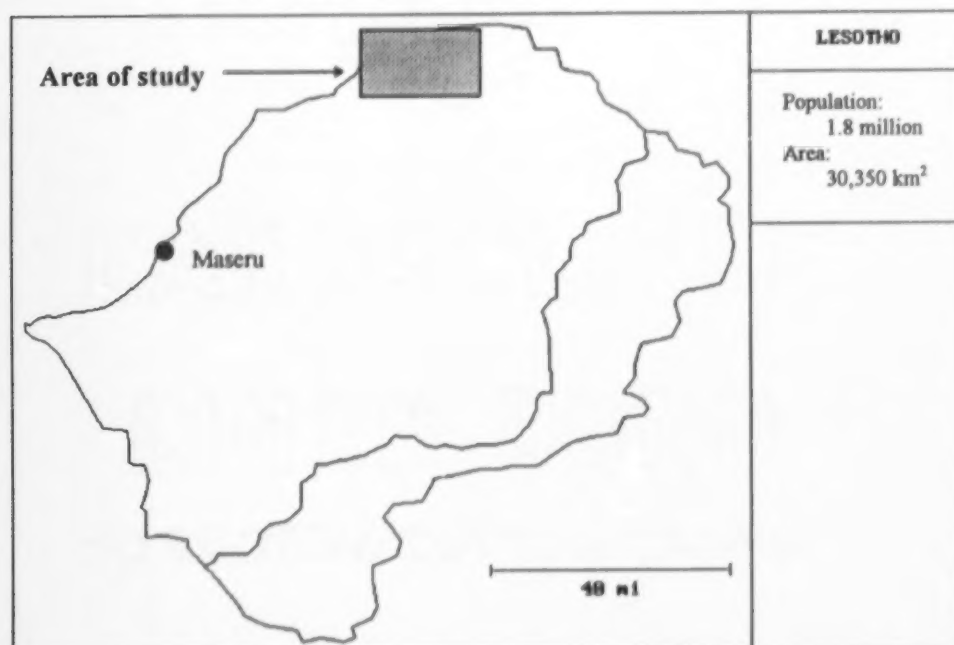
The author spent six months (June to December 1993) in Lesotho, Africa surveying literature; conducting farm household surveys; and consulting with farmers, agricultural specialists, an agricultural economist, a soil scientist, and others working in the field of land conservation. Two pilot studies, each involving 20 farm households, were initially conducted in the Maseru and Mohale's Hoek districts of Lesotho. Social and economic data were collected on family statistics (e.g. family size, composition, work duties), crops grown, field size, capital application, production constraints, and so forth (see appendix one and two). As a result of these two studies, revisions to the final questionnaire (appendix one) and interviewing techniques were made.

Prior to conducting the final survey, two Basotho assistants received a brief training session on the nature of information to be collected. Both assistants had participated on a pilot study conducted two month earlier. The author and a soil laboratory assistant, participated in the collection of field data.

The final survey was undertaken near Ha Mopeli (approx. 1,650 metres) in Berea district and near Nqechane (approx. 1,600 metres), Lithabaneng (approx. 1,900 metres) and Malesaona (approx. 1650 metres) in Leribe district (see figure 1.2. below for area study was undertaken). All four communities are in the north-east lowlands area of Lesotho; Lithabaneng is on an elevated plateau. All study areas are similar in

temperature with night-time, winter lows getting down to about -2°C and up to 16 or 17°C by mid-day. In the summer months, the daily high temperatures are in the $26-28^{\circ}\text{C}$ range. Although first frosts generally occur in May, they can be recorded as early as February or March. The last month to have experienced frost was September in both Leribe and Butha Buthe districts in 1990. All four areas are similar in rainfall measurements: a severe drought had a dramatic impact on production in Lesotho for 1991/92 and 1992/93, the year from which the survey data is derived.

Figure 1.2. Map displaying highlighted area of study (adapted from PC Globe map, © 1992 PC Globe, Inc.)



Survey respondents were divided into two groups: the first a random collection of households in each survey area; the second, a random selection of households from a list of farms where a bio-intensive farming system known as the

Machobane Farm System was employed. Conducting the surveys generally entailed an initial visit with the local chief where our survey requirements and intentions made clear. Of the total 97 surveys undertaken, twelve observations, where a sharecropping arrangement was in effect, were discarded. The reason for this relates to the potential for sharecropping villagers to have less regard for the environmental impact of their farming activities since the land they cultivate is not their own.

Data collection was broken down into two separate tasks. Two survey assistants conducted interviews with Machobane farmers who had been pre-selected in a randomized list. Of the 85 surveys used in the data analysis, 37 involved Machobane farmers, with the remaining 48 farm households practicing a more traditional form of agriculture. Once in the village, farmers practicing more traditional farming systems were selected in a random manner (by drawing names where possible, or by randomly selecting households). Once a household interview began, a nearby field was identified and shown to the author and soil lab assistant whereupon an analysis of certain factors was undertaken (see below).

About three-quarters of the survey questionnaires were undertaken in groups of four or more households. The purpose of using the group survey format was threefold. In explaining a question to one, latter respondents could be clear about the requested information and reply with greater speed and, presumably, greater accuracy. Secondly, it was felt that peer participation could enhance the validity of some responses. Lastly, it provided what the author and survey assistants felt was a positive social context in which to undertake the surveys. For questions relating to

more sensitive issues (e.g. family income), or where opinions, easily biased by group dynamics, were solicited, the survey assistants took respondents aside, one on one. Farm families that participated in the survey were provided with a copy of the results of a soil sample analysis from their field and a means to follow up on the information contained therein.

In the survey questionnaire, values for the following variables (included in the production model outlined in chapter four) were determined: crop output by type and mass (kg.); farm capital owned by type and number; labour supply by number of on- and off-farm family members, age, gender, health status, and employment; and fertilizer application by amount applied per field. The value of output (primarily maize and sorghum) is an aggregate measure of the all crop output in the selected agricultural field. Economic valuation of outputs and inputs at existing price levels was subsequently determined. Other factors included in the analysis in chapter four but not applied in the production model were: household wealth; formal education level of first and second household head; gender of household head; conservation effort (digging of diversion ditches, applying manure to fields, and overall conservation work specified in hours per year); household relationship with village chief (i.e. political connection with land-giving authority); and concern for land erosion relative to other production constraints (see figure 4.1). For a more thorough exposition on the contents of the survey questionnaire see appendix one and two.

Once an agricultural field, farmed by a household participating in the survey, was identified, the following field analysis was undertaken. The area of the field was

measured by pacing and geometric estimation because of the irregular field shapes. The general slope of the field was determined with the use of an Abney level. Soil depth was determined with the use of a soil auger. Soil samples were collected using a soil sampling probe. Twelve samples (30 cm. deep) were collected in various sections of the field using the probe. All twelve samples were placed in a single plastic bag. The contents of the bag were subsequently mixed to blend the sub-samples into one representative composite soil sample for the field. The composite samples were then taken to the Soils Laboratory at the Agricultural Research Division of the Ministry of Agriculture, Lesotho. There they were tested for phosphorus and potassium concentration levels, organic matter content (percent), and pH level.

1.6. ORGANIZATION OF THESIS

This study contains five chapters and six appendices. Following this introductory chapter, basic issues relating to land conservation and soil quality are discussed from a soil science and economic perspective. Chapter three outlines theoretical and mathematical components of production analysis and discusses some of the practical aspects of applying such an analysis to a developing world context. Chapter four is devoted to an empirical analysis of data collected for this study. A conclusion to the theoretical and analytical work is presented in chapter five.

CHAPTER TWO

SOIL: PHYSICAL AND ECONOMIC ASPECTS

2.1. SOIL CONSERVATION AND DEGRADATION

The abuse of agricultural land in hot, arid climates primarily through overgrazing and over-cultivation of nutrient deficient soils, has resulted in severe land degradation and desertification (Horowitz and Salem-Murdock, 1987). Removal of trees and shrubs for agricultural land increases erosion rates, decreases the supply of organic matter, and also removes important shading and sheltering properties, among other soil fertility-enhancing processes (Anderson 1986). Less deleterious, however still damaging to the rural and semi-urban environment, is the consumption of tree stocks for cooking (firewood is used for cooking by 90% of the general African population; Anderson, 1986). By volume, tree clearing and consumption combined exceed incremental growth by 70% in Sudan, 150% in Ethiopia, and by 200% in Niger (Anderson 1986).

For purposes of definition, the term land degradation is used to define the physical removal of soil and the breakdown in physical, chemical and biological properties that are beneficial to plant growth. Erosion, a term often used interchangeably with land degradation, denotes the more specific notion of the physical removal of soil by wind or water and downward movements of topsoil particles to

subsoil formations. In some cases the the term is used to denote a reduction in soil fertility. Usage of these terms vary in the relevant literature.

Declining fertility causes the soil to be worked more intensively to produce the same output as in previous years, further advancing degradation to the point where a soil's fertility can become permanently impaired (Lamprey, 1983). Factors affecting the present and future productivity of soils are numerous; interrelationships of principal factors affecting soil quality are presented below (extracted from Arshad and Coen, 1992, p. 26). Certain variables are beyond human manipulation, others can be influenced by farmers, extension agents, and policy makers.



Figure 2.1 Principal components and interrelationships of factors influencing soil quality.

Declining soil quality, associated with erosion, was first perceived as a primary obstacle to Lesotho's socio-economic development some sixty years ago (Pim, 1935). Harrison (1989) concludes that erosion is one of the most serious problems facing Lesotho. Although concern for accelerated soil degradation (caused through human activities) had been reported as early as 1833 in Lesotho (Germond, 1967), efforts to deal with the problem began in earnest only in the late 1920's (Annersten, 1986). A Sechaba Consultants working document (Hall, 1990) produced the following comments:²

The soils of Lesotho are unusually prone to erosion. On the eroded slopes of the mountains, there is little to contain heavy downpours which result in massive sheet erosion. In the lowlands, the soils which are dominated by impervious duplexes [clay pan below shallow topsoil layer], generally hold little water so the runoff is high and results in widespread gully erosion. This proneness is further exacerbated by cyclical drought that occur every ten years or so.

National soil and water conservation programs have consequently become "the single most expensive and...longest duration set of agricultural development-related programs" (Nobe and Seckler, 1979).

The initial conservation work undertaken by colonial administrations in Africa was geared towards persuading farmers to adopt conservation measures; racial discrimination and unpopular restrictions ensured that the programs would break down at the time of independence (Annersten, 1986). After independence was achieved in 1966, the new administration continued efforts to halt land degradation through food-for-work schemes and national holidays devoted to conservation work. Both achieved little more than temporal commitments (John Gay, 1984). In spite of these efforts, the

² Authors cite Schmitz and Rooyani (1987) and Harrison (1989).

deleterious impact of land degradation on agricultural production in Lesotho continues to worsen:³

The...decline in crop production, with many fields being completely depleted of nutrients by mono-cropping, erosion and lack of organic matter...is well documented...The decline in agriculture is closely related to environmental degradation.

Outside observers suggest that the overcrowding of land by both people and animals, over-cultivation, and neglect for the land in Lesotho must be halted and conservation measures adopted. "They make strong recommendations concerning grazing control, reduction of cattle, building of terraces, fallowing of land, use of grasses and reduction of communal grazing... [meanwhile farmers]...appear to have an entirely different set of concerns, priorities and answers" (John Gay, 1984).⁴ In a survey undertaken by John Gay (1984),⁵ farmers were asked about their general concerns (without any categorization or prompting). None mentioned erosion. When farmers were asked about their concerns with crop farming, again none mentioned erosion. When the question was narrowed further to specific problems in farming, observed changes in farming, and what is necessary to successful farming, only one out of 31 farmers suggested that erosion was a problem. Furthermore, not one farmer considered erosion to be responsible for crop failure. Farmers responded to the question of why their crops had failed as follows (John Gay, 1984):

³ Gay, John, Gill, D., Green, T., Hall, D. Mhlanga, M., Mohapi, M., 1991. Poverty in Lesotho, A Mapping Exercise. Document by Sechaba Consultants (Submitted to Food Management Unit, Gov't of Lesotho).

⁴ N.B. In referencing John Gay and Judy Gay first and last names are used.

⁵ The article was written by John Gay in 1977, but did not appear in print until 1984.

REASON	PERCENT
no answer	36.2
late farming	10.4
poor soil	6.9
frost	5.1
too much rain	1.7
no rain	25.8
no fertilizer	10.4
poor farming	5.1
poor weeding	3.4
worms	1.7

Table 2.1 Table of farmers explanations for crop failure (31 observations; John Gay 1984).

Majoro Moeketsi (Ph.D.), an agricultural economist and professor at the National University of Lesotho (NUL), suggests that farmers see the problem not in terms of erosion but rather in terms of "weak soils" (personal communication, 1993). Weak soils are taken as soils low in fertility. Adopting this perspective, the categories *poor soil* and *no fertilizer*, which sum to 17.3% of all responses, suggest that farmers may actually rate soil quality problems as a significant cause of crop failure.

Qalabane Chakela (Ph.D.), a professor of Geography at NUL, provided a socio-historical perspective on land degradation (personal communication, 1993). He first suggested that a modernizing society "eroded farmers' ability to solve their own problems." The migrant labour system and cash economy are seen to be the principal causes of a breakdown in village cohesion. The emergent individualistic culture cannot provide the necessary care to sustain the agricultural land base. Chakela cited many de facto changes in the rural society – for example, the changing role of the chief during and after the colonial era and other policy-driven changes – which have

conceivably impacted the farmer-land relationship. Many of professor Chakela's ideas would receive more attention were they not beyond of the scope of this paper.

2.2. THE ECONOMICS OF LAND CONSERVATION: BASIC ISSUES

Land tends to be allocated to its best use which may be defined as the use accorded the highest net potential earnings (Nobe and Seckler, 1979). Nobe and Seckler (1979) have adapted a model from Barlowe (1958) which provides an index of land use capacity (see fig 2.1. below). The relative ability of different land sites to yield an economic return determines its end use. Rural land falls into one of three categories: cropland and arable pastures, forestry and grazing areas, or wasteland.

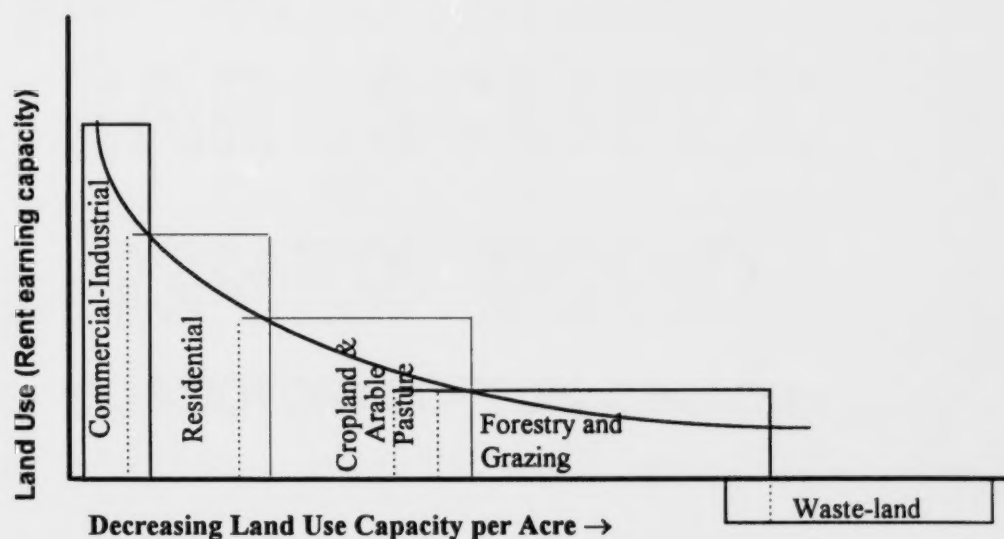


Fig. 2.2 Land value (rent earning capacity) as expressed by land usage categories.

Nobe and Seckler suggest that the cost effectiveness of conservation programs "should be indicated by the relative budget and manpower requirements to achieve adequate levels of protection for various land capability classes in specific uses...."⁶

With two-thirds of Lesotho mountainous, the arable fraction of the 3,035,500 hectares that span the nation is small: only 450,800 hectares (or 14.85%) were under cultivation in 1960. By 1989, the land area under cultivation was reduced to 301,369 hectares (or 9.93% of the total land base), a 33% decrease.⁷ Not surprisingly, an increase in the total stock of cattle has been reported: from 465,500 in 1974 to 583,260 in 1989, a 25% increase (Bureau of Statistics, 1990). The stocking rates for sheep and goats, which outnumber cattle three-to-one and two-to-one respectively, are close to levels recorded twenty years ago (Bureau of Statistics, 1990). These figures suggest that a change in land usage has occurred; some changes possibly arise due to declining soil quality.

One problem with an inventory approach to land usage, however, is that the cause of change may be uncertain: Was there a change in the relative price levels of livestock and crop output? Was there a change in off-farm employment patterns?⁸ A more direct and accurate means of assessing changes in land quality for conservation programs or other purposes could be achieved through studying physical, chemical, and biological changes in soils on cultivated land (Granatstein and Bezdicek, 1992).

⁶ p.10, Nobe and Sekler, 1979. *An Economic and Policy Analysis of Soil-Water Problems and Conservation Programs in the Kingdom of Lesotho*, Ministry of Agriculture, Lesotho and Department of Economics, Colorado State University.

⁷ Estimates by the Range Management Unit, Conservation Division, MOA (reported in Lesotho Agricultural Situation Report, 1990 Edition, Bureau of Statistics, Ministry of Planning)

⁸ Nobe and Secklar (1979) also discuss the implications of soil depth on production and go on to discuss the value of conservation based on changes in this soil quality attribute at the margin.

While a cross-sectional study would not provide the necessary data base to permit a dynamic study of the implications of time on conservation and land degradation, it remains possible to assess soil quality as a function of output or productivity through regression analysis (Wilson et al., 1991; Lindstrom et al., 1991; Izaurrealde et al., 1994). Research work tracking an acceptable soil quality variable would be an important first step towards establishing appropriate, ameliorative management practices (Janzen et al., 1992). The nature of such a variable is discussed in the next section.

2.3. SOIL QUALITY

Declining soil quality through "adverse changes in its physical, chemical and biological attributes" is a global phenomenon (Arshad and Coen, 1992). In general, soils at greatest risk are in developing countries (Blaikie, 1985). Measuring the magnitude and trends in regional land degradation, and understanding processes that precipitate declining soil quality, can only be achieved through the application of an acceptable soil quality variable. While the importance of establishing regional soil quality indices is well established (Granatstein and Bezdicek, 1992; Arshad and Coen, 1992), the means of establishing such an index is a controversial issue. "Lack of a scientifically established criteria [of soil quality] is adversely affecting the design and evaluation of meaningful soil management programs" (Granatstein and Bezdicek, 1992; see also Karlen et al., 1992).

2.3.1. EXISTING SOIL QUALITY MEASUREMENTS

While the primary role of soil may be to sustain plant growth (Nobe and Seckler, 1979), it also serves to reduce atmospheric carbon dioxide accumulation, and purify ecosystems through the decomposition and recycling of wastes (Janzen et al., 1992). While the "specific soil constituents that dictate soil quality have not been well-defined...[an acceptable concept] should be defined within the context of the functions ascribed to the soil" (Janzen et al. 1992). Arshad and Coen (1992) suggest that, "soil quality can be expressed in terms of the sustaining capability of a soil to accept, store and recycle water, minerals and energy for production of crops at optimal levels while preserving a healthy environment. Key attributes of soil quality include physical, chemical and biological properties" (p.25).

What defines the capacity for land to produce food and fibre is referred to as soil productivity. Included in the concept of soil productivity are variables beyond the control of farmers: sunlight, heat, water, and landscape (Janzen et al., 1992; Hausenbuiller, 1978). Soil fertility, a variable more amenable to a farmer's control, refers to the "potential for a soil to supply nutrient elements in amounts, forms and proportions required for maximum plant growth" (Hausenbuiller, 1978). Measurements of soil quality that have been used for research purposes include organic matter, organic nitrogen, electrical conductivity, fertility, microbial respiration or biomass, nutrient release characteristics (e.g. N mineralization potential), enzyme

activity, porosity, hydraulic conductivity, particle size distribution, mineralogy, lime content and pH levels.⁹

Janzen (1992) suggests that organic matter content is perhaps the most commonly used soil quality variable because it is easily collected and quantified; its contribution to nutrient availability, soil structure and water retention is well established, and it is subject to change as a function of management practices imposed on the soil. In a study on the effects of simulated erosion, Izaurrealde et al. (1994) demonstrated the correlation between crop productivity and topsoil depth. Yield reductions were associated with nitrogen and phosphorus removal, and erosion reduced not only the amounts of available nitrogen, but also the soil's ability to release it. A brief discussion of physical, chemical, and biological factors that affect soil quality, highlighting those applied in the empirical section of this study, is provided in the next section.

2.3.2. PHYSICAL, CHEMICAL AND BIOLOGICAL COMPOSITION OF SOIL

In a physical sense, soils are composed of a solid, liquid and gaseous phase (Harpstead et al., 1988). The solid phase, responsible for providing nutrients and an anchoring medium for plants, accounts for about half of soil volume. The major component of the solid phase is matter derived from weathered rocks. These particles vary in size from microscopic clay and silt particles to sand which is visible to the naked eye.

⁹Janzen et al., 1992, citing Campbell, C.A., Zentner, R.P., Janzen, H.H., Bowren, K.E., 1990. *Crop Rotation Studies on the Canadian Prairies*, Research Branch, Agriculture Canada.

The texture and structure of soils are important physical properties. Texture defines the soil in terms of its proportional content of sand, clay, and silt in the mineral component of soils. The structure of soils refers to the manner in which individual particles become grouped together in aggregate form. Texture is seen as a useful indicator of soil quality as it "correlates with and can be used to make various judgments about other physical, chemical, and biological soil properties" (Hausenbuiller, 1978). Other characterizations of the physical properties of soil include consistence (the reaction of a soil to compression or shearing forces), pore space, soil density, and colour. Tests of the physical properties of soil believed to be highly representative of soil quality (Arshad, personal communication, 1993) include: bulk density, water content and water-filled pore space determination, as well as infiltration, soil water-holding capacity, and soil respiration determination.¹⁰

In the liquid phase of soils, water is important in its contribution to the cellular growth of plants and is involved in the uptake of soil nutrients by plants. The prime constraint on global plant growth is probably caused by limited water supply (Hausenbuiller, 1978). The effectiveness of water is limited by the porosity and drainage capacity of the soil.

Pore space, which accounts for 40 to 60 % of soil volume, determines the oxygen and water retaining capacity of a soil (Harpstead et al., 1988). Of four gases contained in soil pores (N_2 , O_2 , CO_2 , and water vapour), oxygen (O_2) is the most important (Mill and Donahue, 1990). Oxygen provides energy primarily through

¹⁰Two of three tests recommended by USDA NPA SPN Research, as faxed to the Soil Science Dept, University of Alberta, Alberta, Canada.

oxidation of carbon compounds to carbon dioxide and water. While nitrogen cannot be used in gaseous form, it can be used by some soil microbes and then appear in organic matter where plants can benefit from its presence.

The formation of any soil is therefore a unique function of the parent material from which it derived, circumstances affecting the liquid and gaseous phases within the soil, and time. The formation of soil can be viewed as a conversion process with parent material (rock) at one end of the spectrum, and topsoil at the other. Different bands on the conversion spectrum, commonly referred to as soil horizons, are readily observed on eroded landscapes where a cross-section of the soil layers is exposed. Mineral weathering, organic matter accumulation, downward movement of microscopic soil particles (primarily clays), and the accumulation of these particles in a subsurface layer appear to be the primary processes determining the nature of horizontal layering of soils (Hausenbuiller, 1978). Five soil-forming factors primarily responsible for the development of topsoil are parent material, climate, biota (living organisms and organic residues), topography, and time (Miller and Donahue, 1990). The rate of conversion of parent material into soil varies with the depth of topsoil, with shallower soils experiencing higher rates of conversion because of the greater exposure of subsoils to erosive agents (Miller and Donahue, 1990).

Soil horizons are generally characterized, in descending order, as A, B, or C, with sub-regions for each horizon. Any given soil may or may not have all such layers and sub-layers present. Zone A, often referred to as topsoil, is characterized as a region where the maximum effects of organic matter accumulation, mineral weathering

and clay loss are observed. A layer of plant residue on the topsoil is referred to as the O horizon. A region where a maximum loss of organic and inorganic material occurs is referred to as the Ae layer. Below this lies zone B, which, in Lesotho is typically a region of maximum clay accumulation. The lowest layer, zone C, is generally classified as a region of minimal change. Plant growth is primarily dependent on the quality of soil in zone A, but drainage and future soil generation are influenced by the lower horizons.

As mentioned earlier, soil quality is a partial function of the depth of the A horizon of a soil (Izaurre et al., 1994; Malhi et al., 1994; Alt et al. 1989). The average topsoil depth in Lesotho has dropped from 38 to 28 cm during this century (Harrison 1987). Harrison states that this rate of depletion is excessive, estimating that it takes each centimetre of soil at least a century to form. In Iowa, however, it was shown that 10 cm of topsoil could develop on 60 cm of a subsoil over the same period of time (Hallberg et al., 1978). This phenomenon likely occurs due to the effects of different climatic conditions and the presence of dissimilar parent material.

The rate at which natural erosion in the American plains is believed to occur is, on average, 1.12 tonnes per hectare annually, but that rate can go up by a factor of 10 to 100 times when soil cover is lost (Troeh et al., 1991). Estimated soil-loss tolerances – defined as the maximum soil loss rate which, if held constant over time, continues to allow high levels of crop productivity to be maintained indefinitely (Wischmeier and Smith, 1978) – range between 4 and 13 metric tonnes/hectare/year.

Such estimation variance renders the formulation of a general tolerance level impractical (Troeh et al., 1991).

Results from several analyses (see for example: Janzen et al., 1992; Lindstrom et al., 1992; Kinako, 1983; Arshad and Coen, 1992) suggest that although soil depth is a good proxy for a soil quality measurement, it is not complete. Research work conducted for this paper supports that claim. In assessing soil quality, physical, chemical and biological properties of soils augment soil depth.

The chemical factor of soil quality relates to the presence of micro- and macronutrients essential for plant growth. The latter are taken up by plants in relatively large amounts and are responsible for forming much of a plant's biomass. Micronutrients are utilized in trace amounts and are often more important for facilitating necessary soil reactions such as oxidation-reduction. Table 2.1. below provides a comprehensive list of 16 essential micro- and macronutrients. All these nutrients are contained in soils with the exception of oxygen (O₂) and nitrogen (N) which are derived from the air, and hydrogen (H) from water.

Table 2.2 Macro- and Micronutrients of soil.

Macronutrients			Micronutrients		
Carbon (C)	Potassium (K)	Hydrogen (H)	Iron (Fe)	Copper (Cu)	Manganese (Mn)
Calcium (Ca)	Oxygen (O ₂)	Magnesium(Mg)	Zinc (Zn)	Chlorine (Cl)	Molybdenum (Mo)
Nitrogen (N)	Sulphur (S)	Phosphorus (P)	Boron (B)		

These elements are taken up by the root system from the soil but where the soil does not supply optimal amounts of one or more element in a form plants can absorb, some

constraint on crop output exists (van Keulen and Wolf, 1986). The two macronutrients recorded in the data collection for this study were phosphorus and potassium. Both have relatively low mobility in soils.

"In many parts of the world, crop production is limited by phosphorus availability" (van Keulen and Wolf, 1986). One kilogram of P taken up by a rice crop on a per hectare basis translated into an increase in grain production of between 410 and 625 kg (based on studies from Dash et al., 1982; Traoré, 1974; Bredero, 1966; Sadanandan et al., 1980; Agarwal, 1980; Motsara and Datta, 1971). For Cassava, the same kilogram of P appears to produce an additional 230 to 510 kg of tuber dry-matter on one hectare of land (based on studies from Mahapatra and Panda, 1972; Beye, 1974; Esakkimuthu et al., 1975; Agarwal, 1980). Other studies revealed that one kilogram of P uptake per hectare leads to between 420 and 590 kg of additional maize grain production (based on studies from Traoré, 1974; Kang and Yunusa, 1977; and Suwanarit, 1975). In Lesotho, phosphorus deficient soils are widespread (Moea Mafolo, Director of Soils Laboratory [MOA], personal communication, 1993).

The high acidity (or low pH levels) of Lesotho's soils contributes to a regional phosphorus deficiency. In acidic soils, phosphorus tends to form into insoluble phosphates that plants cannot utilize. In addition, a positive relationship exists between either moisture levels or nitrogen concentration and the concentration of P in soils (van Keulen and Wolf, 1986).

The concentration of potassium in soils is primarily a function of their mineralogical composition (van Keulen and Wolf, 1986). The uptake of K has also

been linked to production levels. For rice production, a one kg increase in K uptake per hectare lead to a 55 to 80 kg increase in rice yields (based on studies from Mahapatra and Panda, 1972; Beye, 1974; Esakkimuthu et al., 1975; and Agarwal, 1980); and 40 to 110 kg increase in Cassava yields (based on studies from Nijholt, 1936; Kanapathy, 1974; and Dufournet and Goarin, 1957).

Crop residues left behind at harvest time contain most of the K taken up by plants. In the case of a pastoral country such as Lesotho, these residues may however be grazed upon by livestock. An endemic shortage of firewood suggests that a considerable proportion of livestock dung may be removed for home cooking. The lower stalks of maize, which livestock cannot digest and which certainly contain potassium, may remain in the soil in Lesotho for years before breaking down due to low levels of microbial activity (David May, personal communication, 1993). Higher temperature and moisture levels favour the weathering process that makes K available to plants; the availability of K can therefore vary from year to year (van Keulen and Wolf, 1986).

The pH levels of soils can be "used to indicate the chemical status of soils as it affects many biological processes, including plant growth" (van Keulen and Wolf, 1986). The pH level indicates the concentration of H^+ ions in the soil, or more simply, whether a soil is acid, neutral, or alkaline. Soil pH greatly influences the availability of P through its influence on the presence and solubility of calcium, iron, and aluminum, and its effects on bacterial growth (Miller and Donahue, 1990). Alkaline soils form primarily where poor tilth disables exchangeable sodium ions from maintaining a well-

structured soil. The impact of excessive alkalinity or acidity on crop productivity is generally negative. Two other important chemical characteristics (Harpstead et al., 1988) which affect plant growth – salinity and sodicity – refer to salt and sodium concentrations in soil.

Organic matter affects the physical and chemical processes in a soil, yet is formed primarily as a result of biological processes. It is formed in upper soil layers initially from plant residue with later contributions from microbes, insects and other animals. The presence of organic matter is generally evident by its darkening effect on soils associated with high fertility. Like clay, organic matter has dominantly negative-charged surface particles that retain elements (calcium, magnesium, etc.) and compounds which are the basis for much of the soil fertility upon which plants depend (Harpstead, 1988). These charges help determine water retention and ionization levels and the extent to which soil particles cling together.

Humus, the semi-stable portion and principal component of organic matter, generally improves the physical properties of soils. By virtue of its binding action, it helps to mitigate erosion rates; it increases the friability of stiff, tight soils; and, it also increases the volume proportion that pore space occupies in soil. Humus also contains organically bound nutrients, notably N, P, and S (van Keulen and Wolf, 1986) which are released over time.

In conclusion, plant growth is a function of many soil variables and extraneous factors. The depth of topsoil determines the extent to which roots can exploit essential soil nutrients, but only portrays a limited view of soil quality. Soil sampling

can provide other quantitative measures, which, together with soil depth may form the basis for an acceptable soil quality variable that can be tested through statistical or econometric analysis.

2.4. SOIL QUALITY IN AGRICULTURAL PRODUCTION

A number of papers have been written on the correlation between soil quality attributes and production. They are typically taken from a soil science perspective whereby biomass production or crop yields are regressed on soil characteristic variables such as nitrogen levels, organic matter content and so forth (see for example: Karlen et al., 1992; Robbins and Voss, 1991; Izaurralde et al. 1994). The lack of any internationally, or even regionally-determined, indexed measurement of soil quality (Arshad and Coen, 1992) is in part due to the variable response of different crops to different soil characteristics. A suitable example is provided by Dinar et al. (1990). The authors estimated a quadratic equation where the t-statistic for the coefficient of a soil salinity variable demonstrated positive, significant correlation to the dependent variable, wheat production. When sorghum yield is taken as the dependent variable, however, the same variable is again significant, but its coefficient becomes negative.

Jones and O'Neill (1992) established a system of equations to analyze the effects of selected variables on land degradation. In the paper the authors also hypothesized on the causal relationships between a number of economic and environmental variables. The notion of an environmental degradation index value – adversely impacted by production activities, positively impacted by conservation

efforts – is proposed. The authors contribute a new systems perspective to analyzing economic influences on land degradation, however, the nature of what constitutes a degradation index is not specified.

Standard economic treatment of soil quality has typically related it to its simplest form: soil depth. The impacts and cost implications of reductions in topsoil depth through soil and wind erosion has received considerable attention (see: Van Kooten et al. 1989; Van Vuuren and Fox, 1989; Hudson, 1981). Estimates vary depending on whether externalities and redeposition of eroded material (Lerohl et al., 1990) – which would intuitively enhance productivity of lower-lying areas – are included in the analysis. The methodologies for determining the cost of erosion also vary. It could be measured as the cost of fertilizers to hold productivity levels constant while topsoil diminishes (Sparrow et al., 1984) or alternatively as the differential value of production over time between the non-eroded and eroded farmland scenario (Van Kooten et al., 1989). One analysis puts the annual value of lost production due to soil degradation at C\$239 million (Sparrow et al., 1984), another study (Van Kooten et al., 1989) suggests a more diminutive figure of C\$36 million. The conclusion from a study where the Erosion Productivity Impact Calculator (EPIC) was applied to an Albertan farmland scenario suggested that productivity losses caused by erosion over a 50 year period are minimal (Lerohl et al., 1990). The conclusions for Lesotho and much of the developing world, as suggested in chapter two, may not be the same.

CHAPTER THREE

PRODUCTION ECONOMICS

3.1. PRODUCTION FUNCTIONS

A *definitional equation* sets up an identity that explains an exacting relationship: e.g. profit equals revenues less all costs. A *behavioural equation* describes or approximates the manner in which a variable, say wheat production, behaves in relation to other variables such as labour application (Chiang, 1984). Estimated production functions are behavioural equations devised to approximate the relationship between variable and fixed inputs and outputs. Production choices and economic decision rules depend on the nature of the physical properties that underlie the production process (Beattie and Taylor, 1985). The choices open to farmers are limited and vary from farm to farm, some being more constrained than others in their selection of input combinations.

A production function is a mathematical representation of a physical process. As such, it possesses different characteristics and limitations depending on the applied functional form. For illustrative purposes, consider production as a function of the single most limiting factor input. A simple, single-variable linear equation may work reasonably well insofar as production does not depend on other inputs. A conceivable representation of this proposition may take on the mathematical form of $y = ax^\gamma + c$ where x is a factor input involved in the production of y , and a , γ , and c are model

parameters. Normally, however, production models include more than one key factor input: land, labour, capital, and management inputs are among the most common; all are associated with scarcity and have alternate uses (Sankhayan, 1988). As these variables depend, to a large extent, on human decisions, they are often of greater interest to analysts than variables, such as rain, which are beyond human control.

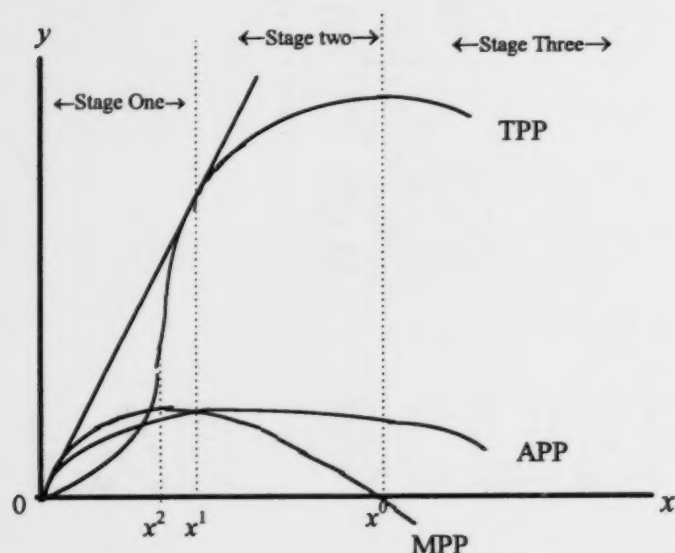


Figure 3.1 Three stages of production; marginal, average and total physical product.

The above diagram reflects the classical three-stage production perspective for the relationship between a single input (x) and output (y). TPP represents total physical product: the output value that corresponds with the respective level of input x . APP represents the average physical product: total output divided by the corresponding input value. MPP represents the marginal physical product: incremental gain in output production due to a unit increase in input level. The shape of the TPP

curve – a function of the productivity relationship between the x input and y output – determines the shape of the other two curves: MPP is $\partial \text{TPP}(y)/\partial x$, APP is $\text{TPP}(y)/x_i$ at each x_i value.

The shape of the TPP curve in figure 3.1 reflects the notion of initially increasing returns to scale for factor input x_i (stage one) followed by decreasing returns to scale, but positive MPP (stage two), and lastly, decreasing returns to scale and negative MPP (stage three). If a producer has free access to x , it could be applied to the point where MPP is zero. The more realistic scenario where a cost is associated with x , suggests that input application will occur until MPP is equated to marginal cost. While the concepts behind the shape of the TPP curve are basic, the diagram serves to simplify the underlying economic considerations of production analysis: factor elasticity, function coefficient elasticity, rate of technical substitution, and elasticity of factor substitution.

Factor elasticity (E) is defined as:

$$(3.1) \quad E = (\% \text{ change in output}) / (\% \text{ change in input})$$

$$(3.2) \quad E \equiv (dy/y)/(dx/x) = (dy/dx) \cdot (x/y)$$

$$(3.3) \quad \therefore E = \text{MPP}/\text{APP}$$

Factor elasticity is a measurement of the impact an infinitesimally small increase in input level has on output production. For a quadratic function:

$$(3.4) \quad y = a_0 + a_1x_1 + a_2x_2 + \frac{1}{2}b_1x_1^2 + \frac{1}{2}b_2x_2^2 + b_3x_1x_2,$$

$$(3.5) \quad \text{MPP}_1 = \partial y / \partial x_1 = a_1 + b_1x_1 + b_3x_2$$

$$(3.6) \quad \text{APP}_1 = y/x_1 = (a_0 + a_1x_1 + a_2x_2 + \frac{1}{2}b_1x_1^2 + \frac{1}{2}b_2x_2^2 + b_3x_1x_2) / x_1$$

$$(3.7) \quad E_1 = (a_1x_1 + b_1x_1^2 + b_3x_1x_2) / (a_0 + a_1x_1 + a_2x_2 + \frac{1}{2}b_1x_1^2 + \frac{1}{2}b_2x_2^2 + b_3x_1x_2).$$

C.W. Cobb and P.H. Douglas, in their 1928 paper, "A Theory of Production," proposed a production function with emphasis on readily derived technical relationships. The article outlined perhaps the most "ubiquitous" function in all economics, and "touched off a spate of empirical studies that has not yet truly abated" (Chambers 1988). The "Cobb-Douglas" function is one of the most widely used functions in estimating production relationships in both industry and agriculture (Sankhayan, 1988). When the Cobb-Douglas function, of form $y = Ax_1^{b_1}x_2^{b_2}$, is applied in econometric analysis, the b_1 and b_2 parameters can be readily obtained when natural logarithms are applied for both dependent and independent variables:

$$(3.8) \ln y = \ln A + b_1 \ln x_1 + b_2 \ln x_2$$

As shown below, these parameters – input coefficients in estimating format – are, for the Cobb-Douglas function, factor elasticity values:

$$(3.9) E_1 = MPP_1 / APP_1 \equiv (\partial y / \partial x_1) / (x_1 / y)$$

$$(3.10) = b_1 Ax_1^{b_1-1} x_2^{b_2} \bullet (x_1 / Ax_1^{b_1} x_2^{b_2}) = b_1.$$

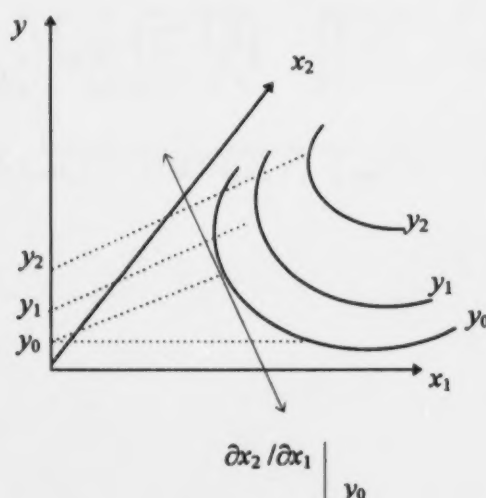


Figure 3.2 Production surface with isoquants (y_0 to y_2) and marginal rate of technical substitution ($\partial x_2 / \partial x_1$).

The manner of interaction between two or more input variables is illustrated in figure 3.2 above. An isoquant is a contour line on the production surface mapping the locus of feasible input coordinates (x_1, x_2) that jointly produce a given output (e.g. y_0 , y_1 , or y_2 as displayed above). The negative value of the slope of each isoquant ($\partial x_2 / \partial x_1$) is the *rate of technical substitution* (i.e. $RTS_{12} = -[\partial x_2 / \partial x_1]$).

The *elasticity of factor substitution* (σ) measures the local substitutability between inputs. Beattie and Taylor (1985) define it as the proportional rate of change of the input ratio divided by the proportionate rate of change in RTS:

$$(3.11) \quad \sigma = [\% \Delta (x_2/x_1)] / [\% \Delta (-\partial x_2 / \partial x_1)]$$

$$(3.12) \quad \sigma = [d(x_2/x_1) / (x_2/x_1)] / [d(f_1/f_2) / (f_1/f_2)]$$

When this is applied to a Cobb-Douglas equation:

$$(3.13) \quad y = Ax_1^{b_1}x_2^{b_2}$$

$$(3.14) \quad dy = b_1 Ax_1^{(b_1-1)}x_2^{b_2} dx_1 + b_2 Ax_1^{b_1}x_2^{(b_2-1)} dx_2 = 0$$

$$(3.15) \quad dx_2 / dx_1 = - [b_1 Ax_1^{(b_1-1)}x_2^{b_2}] / [b_2 Ax_1^{b_1}x_2^{(b_2-1)}] \\ = (b_1x_2 / b_2x_1).$$

Since $(3.16) \quad f_1/f_2 = -dx_2/dx_1$

$\therefore (3.17) \quad dx_2 = - (f_1/f_2) dx_1.$

By substitution:

$$(3.18) \quad d(f_1/f_2) = [\partial (f_1/f_2) / \partial x_1 - (f_1/f_2) \partial (f_1/f_2) / \partial x_2] dx_1$$

Omitting some intermediary steps, we find that:

$$(3.19) \quad \sigma = [f_1f_2(f_1x_1 + f_2x_2)] / [x_1x_2(2f_1f_2f_{12} - f_2f_{22} - f_2f_{11})]$$

For the Cobb-Douglas, this simplifies to :

$$(3.20) \sigma = 1.$$

This implies that the local substitutability between any two inputs is always unitary: neither high, nor low. This restriction led K.J. Arrow, H.B. Chenery, B.S. Minhas and R.M. Solow to develop a modified function known as the Constant Elasticity of Substitution where σ can be set at a value other than unity (Sankhayan, 1988).

A further criticism of the Cobb-Douglas function, in contrast to the quadratic or translog functions, is that it cannot represent changes in MPP ($\partial \text{MPP} / \partial x$ or $\partial^2 \text{TPP} / \partial x^2$) over the entire range of production (Heady, 1952). Depending on the value of the exponents, MPP is either constant, increasing, or decreasing. In figure 3.1 above, the first stage of production occurred where MPP was rising. The second stage occurred where MPP was diminishing, yet still positive; the third stage involved a strictly negative MPP. With the values of b_1 and b_2 typically set somewhere between one and zero, MPP is constrained to exhibit positive ($b_1 + b_2 > 0$), constant ($b_1 + b_2 = 1$), or diminishing returns ($b_1 + b_2 < 0$) to factor application. Defending the applicability of the Cobb-Douglas function, Chambers (1988) discounts the notion of stage three production by pointing out that positive MPP is "almost universally maintained." Ruling out the first stage of production is more difficult: market imperfections, credit and cost constraints, and imperfect knowledge could conceivably result in this phenomenon. A modified Cobb-Douglas model which can reflect all three stages of production is the translog function. Before discussing this function,

however, a brief note on a revised-variable Cobb-Douglas function applied in the econometric analysis undertaken in chapter four is in order.

If an estimating model of the Cobb-Douglas format is applied where certain variables represent the square of the log value (as with the translog function), then the algebraic formulations used to calculate marginal products and elasticity of output or substitution are revised. The estimating equation is no longer

$$(3.21) \ln y = \ln(A) + \beta_1 \ln(x_1) + \beta_2 \ln(x_2) + u,$$

but rather:

$$(3.22) \ln y = \ln(A) + \beta_1 \ln(x_1) \ln(x_1) + \beta_2 \ln(x_2) + u.$$

Taking the antilog of equation 3.22, ignoring the residual (u), generates:

$$(3.23) y = A x_2^{\beta_2} e^{\beta_1 (\ln x_1) (\ln x_1)} = A x_2^{\beta_2} [x_1^{\beta_1}]^{(\ln x_1)}.$$

The marginal physical product for x_1 becomes:

$$(3.24) MPP_1 = 2A\beta_1 x_2^{\beta_2} (\ln x_1 / x_1) e^{\beta_1 (\ln x_1) (\ln x_1)}.$$

The formula for calculating the elasticity of substitution no longer simply equates to one, it becomes a messy formulation several lines long.

The transcendental function, a generalization of the Cobb-Douglas, uses squared log values in its estimating format, and thus the elasticity of substitution value also becomes difficult to calculate. The transcendental function of form $y = a_0 x_1^b e^{ax_1}$, first proposed by A.N. Halter in 1957 (Sankhayan, 1988), was later transformed by Christensen, Lau, and Jorgenson (1973) to become the translog production function. Used in econometric analysis, the translog function is not constrained by the

imposition of constant marginal productivity as with the Cobb-Douglas and the CES estimating equations.

Further advantages for use of the translog relate to its simplified applications to duality theory, translog cost functions, and also for modern econometric theory (Sankhayan, 1988). The estimating form of the translog function can be expressed as:

$$(3.25) \ln y = \ln \alpha_0 + \sum_{i=1}^n (\alpha_i \ln x_i) + \frac{1}{2} \sum_{i=1}^n \sum_{j=1}^n (\beta_{ij} \ln x_i \ln x_j)$$

$$(3.25) \ln y = \ln \alpha_0 + \sum_{i=1}^n (\alpha_i \ln x_{it}) + \sum_{i=1}^n \alpha_{ii} (\ln x_{it})^2 + \sum_i \sum_j (\beta_{ij} \ln x_{it} \ln x_{jt}) + u_t$$

where,

$t = 1, \dots, T$, the number of observations

u_t = a random error term

$\alpha_{ii} = \frac{1}{2} \beta_{ii}$ from first equation

$i, j = 1, 2, \dots, n$ ($i \neq j$)

3.2. VARIABLE AND DIAGNOSTIC TESTING

Two convenient means of testing for a relationship between two variables are contingency table analysis and correlation coefficient determination. Contingency table analysis may be more appropriate where at least one of the variables in question is presented in binomial or multinomial form. In formulating contingency tables, values for two variables are represented as classes in either ascending or descending order. Classes for one variable are placed as horizontal headings, classes for the other are row headings: the intersection of one row and one column is a box where the

frequency of observations of the two coinciding variables is recorded. A positive relationship between the two variables is observed where values in the upper left and lower right sections of the table display higher relative frequencies than elsewhere. This is where a low class observation of one variable coincides with a low class observation of the other and, similarly, where high class observations for both variables also coincide. A chi-square statistic can be calculated to test for a relationship, although it cannot specify the nature of the relationship that exists. The chi-square value is calculated as follows:

$$(3.26) \quad \sum (\text{observed frequency} - \text{expected frequency})^2 / (\text{total frequency})$$

The expected frequency is the product of the row frequency total and the column frequency total divided by the total frequency (i.e. observations).

If two continuous variables are statistically independent, then their correlation coefficient equals zero, a perfect linear relationship exists where a value of one is calculated. The correlation coefficient is the square of the coefficient of determination (r) which is calculated as follows:

$$(3.27) \quad r = \frac{n \left(\sum_{i=1}^n X_i Y_i - \sum_{i=1}^n X_i \sum_{i=1}^n Y_i \right)}{\left(\left[n \sum_{i=1}^n X_i^2 - \left(\sum_{i=1}^n X_i \right)^2 \right]^{0.5} \left[n \sum_{i=1}^n Y_i^2 - \left(\sum_{i=1}^n Y_i \right)^2 \right]^{0.5} \right)}$$

The existence of dependence between variables is desirable when one is the explanatory variable of an estimating equation and the other is the dependent variable. When both variables are independent variables and a moderate to strong correlation is detected through either the correlation coefficient value, or a significant chi-square

value calculated on a contingency table, then multicollinearity probably exists. If, in a model estimated by OLS (ordinary least squares), multicollinearity exists, standard errors are increased thereby reducing t-statistics for coefficient parameters. OLS estimators, however, are still best, linear, unbiased estimators (BLUE). In some cases, the only remedy is to remove certain variables from the analysis. "A number of methods have been suggested in the literature, most of which are ad hoc, and there is not much agreement among econometricians about their usefulness" (Ramanathan, p.242, 1992).

Heteroskedasticity is another problem that can affect the quality of information derived from regression analysis, particularly for cross-sectional data. As multicollinearity violates the OLS assumption of independence among explanatory variables (expressed in an orthogonal covariance matrix), heteroskedasticity indicates a violation of the assumption that the expected value of the error variance (σ^2) is the same over all observations (observed where a single constant value spans the diagonal of the covariance matrix). Where the variance, or the dispersion around the mean, depends in part on the value of the dependent or independent variables, then heteroskedasticity exists. If heteroskedasticity is ignored, OLS estimates are unbiased and consistent, but no longer the best or more efficient than other estimating formats. If the form of heteroskedasticity is known, a generalized or weighted least squares approach can be applied. Generalized least squares (GLS) methods of estimation addresses heteroskedastic tendencies by transforming the values of the explanatory variables and the error term u_i : each term is divided by σ_i , the standard deviation of u_i :

$$(3.28) \quad Y_i = \beta_1 1/\sigma_i + \beta_2 (X_{i2}/\sigma_i) + \beta_3 (X_{i3}/\sigma_i) + u_i/\sigma_i.$$

Where the residual standard deviation is proportional to some known factor (Z), multiplicative heteroskedasticity exists, where

$$(3.29) \quad \text{Var}(u_i) = \sigma^2 Z_i^2,$$

or equivalently,

$$(3.30) \quad \sigma_i = \sigma Z_i.$$

The Shazam (White, 1993) econometrics program option "weight =" for OLS can be used to remedy multiplicative heteroskedasticity when its structure is known. Each observation is multiplied by the square root value of the weight variable (the Z value in equation (3.30) above represents the weight variable) thereby generating a GLS estimating approach.

3.3. AGRICULTURAL PRODUCTION IN LESS DEVELOPED COUNTRIES

T.W. Schultz (1964) is credited with stimulating interest in evaluating the productivity and efficiency of the smallholder farmer in the less developed nations (Baker and Eicher, 1992). Schultz's view of the smallholder farmer as technically inefficient but allocatively efficient, and subsequent supporting empirical work, encouraged further analyses. Many production functions have since been established using survey data which Baker and Eicher (1992) stress has been of "uneven quality...Data problems have forced researchers to rely on inadequate representation of aggregate input categories – land, labour, capital – in estimating interfarm production functions".

Aggregation and misspecification reduces the informative value of production function analysis. Typically, the coefficients of most production functions have been small and the standard errors large when inputs have been aggregated (Baker and Eicher, 1992). Researchers such as Shapiro (1973), Tench (1975) and Rukandema (1978) ceased to rely exclusively on physical variables and turned to alternate variables explaining production. Tench (1975) estimated a production function in Zambia whereby output was regressed purely on social and personal factors. Surprisingly, the multiple coefficients proved to be as large and significant as the coefficients based on the usual physical inputs.

The specification of a production function may be improved through the disaggregation of data. Labour has been divided into family and hired units (Norman et al., 1979) and age-sex categories (Shapiro, 1973; Tench, 1975); cropping operations have been differentiated (Shapiro, 1973; Rukandema, 1978). Even the level of management has been scored for inclusion in a production model, in one case reflecting the degree of modernization (Shapiro, 1973).

In summary, data limitations ensure that the parameters of many production functions are, at best, rough approximations (Baker and Eicher, 1992). Furthermore, the nature of explanatory variables and their functional relationships may differ from those derived through analyses in the developed countries where certain political, economic and social parameters are likely to be different.

CHAPTER FOUR

EMPIRICAL STUDY

4.1. PRELIMINARY CONSIDERATIONS

A primary objective of this chapter is to undertake an empirical, econometric analysis of the nature and role of soil quality in agricultural production. An attempt is made to establish an acceptable soil quality variable in the framework of economic production modelling. Such a variable could be applied on a regional basis to monitor changes in soil quality affected through conservation activities, land degrading practices, or natural processes. The monetary value of changes in soil quality can be assessed by determining:

- the marginal value of soil quality per hectare
- its incremental change over time
- the land area in consideration (hectares)

The bulk of this chapter is geared towards addressing the first point in detail through production analysis, with a brief mention posited on the latter two. Towards this end, the correlation coefficients of six soil quality variables, in relation to agricultural productivity, are determined. Six soil quality variables and other key factors of production (labour, capital, field slope) are then specified in different production functions – linear, quadratic, Cobb-Douglas, and translog – using ordinary least squares (OLS) method of estimation.

A secondary objective is to establish the significance and magnitude that certain socio-economic variables – labour supply, conservation applications, socio-political status, farming systems, and attitude towards land degradation – exhibit in the determination of soil quality through a multinomial logit model. Low chi-square values on cross-tabulation tables suggest that it would be inappropriate to estimate such a model based on the above-mentioned variables. That there is no apparently significant relationship between the specified socio-economic variables and soil quality may be due to data collection errors, inaccurate variable specification, or point to the inappropriateness of applying a cross-sectional data base to assess such relationships. The problems cross-sectional data may present in addressing the primary and secondary objectives are mentioned later in this chapter.

4.2. A CRITIQUE OF APPLIED PRODUCTION VARIABLES

Traditional production function inputs include land, labour, capital, and management variables (Sankhayan, 1988). While Varian (1992) suggests that inputs and outputs should be measured in terms of flows attached to corresponding time intervals, this approach can be particularly problematic in developing countries where prices and rental values can be variable and difficult to discern (see Judy Gay and Green, 1991; Tench, 1975). The difficulty may arise from inefficient market structures or social institutions such as land tenure systems that do not readily lend themselves to neoclassical economic analysis. Furthermore, a profit function is difficult to establish as farming in Lesotho is not typically a commercial venture: from the total sample

population of 97 farm households surveyed for this study, only 28.87% were marketing farm output worth more than \$20.00 (Canadian). Disaggregating and assessing the value of crop inputs, such as seed, for any given field is a practical problem owing to the fact that farmers often own more than one field. The problem is further exacerbated by the application of both saved and hybrid seeds. Difficulty in assessing the exact time labour application occurs due to the survey questionnaire technique of data collection: determining field-specific allocation entails intensive labour tracking methods. Farmers' suspicions about the objective of the survey further complicates the collection of reliable data (personal communication [1993]: Keketso Chalatse, Sello Khalake, Letlamoreng Mosene, Majoro Moeketsi, Thuso Green, Ntate Molapo).¹¹

Establishing the role of soil quality in Agricultural productivity through *standard production analysis* is therefore not feasible for this cross-sectional study. A production assessment geared more towards regressing output productivity on fixed factors such as labour supply (as opposed to application), farm capitalization levels (as opposed to rental and depreciation values), field slope and soil quality becomes a reasonable alternative. One variable input deemed to have been reasonably assessed – fertilizer application – has been included in the analysis. A better specification of this variable appears to be the result of the costly nature of fertilizer input and its monolithic divisibility (i.e. each bag weighing 50 kg).

¹¹ An attempt to establish the values of flow variables was, however, attempted – see appendix one and two.

Before proceeding with variable specification, it should be noted that, from a total of 97 completed surveys, 12 were discarded where a sharecropping arrangement was in effect. Many of the functions employed in this analysis use logarithmic values, resulting in a problem where a variable takes on a value less than one. The natural log of any positive value less than one is negative, but, when squared it becomes positive and particularly large when the original value is close to zero. This specification problem could grossly exaggerate the impact the variable has when applying regression analysis. To avoid this problem, a minimum value of one is specified for all variables with negligible impact.

In applied regression analysis, the explanatory variables, or regressors, used to explain land productivity for this study are: labour supply, farm capitalization value, fertilizer application, field slope, and soil quality. The following signs are anticipated for these explanatory variables:

Table 4.1. Anticipated sign of various production variables

DEPENDENT VARIABLE: LAND PRODUCTIVITY	
LABOUR SUPPLY	+
FIXED CAPITAL	+
FERTILIZER	+
SOIL QUALITY	+
SLOPE	-

4.3. VARIABLE SPECIFICATION

4.3.1. LABOUR SUPPLY

Production economics deals with the application of resources in alternative production processes. Normally, some degree of scarcity is associated with such resources, forcing farm managers to make allocation decisions that will ultimately influence output levels (Beattie and Taylor, 1985). A general absence of scarcity alludes to a lower correlation between the factor in question and cropland productivity. In Lesotho, where 60% of farm households are well-integrated into the wage labour force either in Lesotho or in South Africa (Judy Gay and Green, 1991), labour presumptively appears to be associated with some degree of scarcity. A trend in the reduction of Basotho workers in South Africa, however, can be traced back to the mid-Eighties (Lesotho Statistical Yearbook, Bureau of Statistics, 1992). Two primary reasons are cited: the declining South African economy and policies favouring employment of South Africans over traditional foreign labour pools. That this has contributed to excess labour pools in rural and urban areas is arguable, however, farmers have suggested a general absence of labour supply constraints in their production processes.

When asked about the most serious limitations on agricultural production, respondents ranked 12 constraints from the most imposing to the least significant. The mean score for each of the twelve constraints is presented in the graph below: lower scores depict more serious constraints (seed, drought, and fertilizer) are the three most severe).

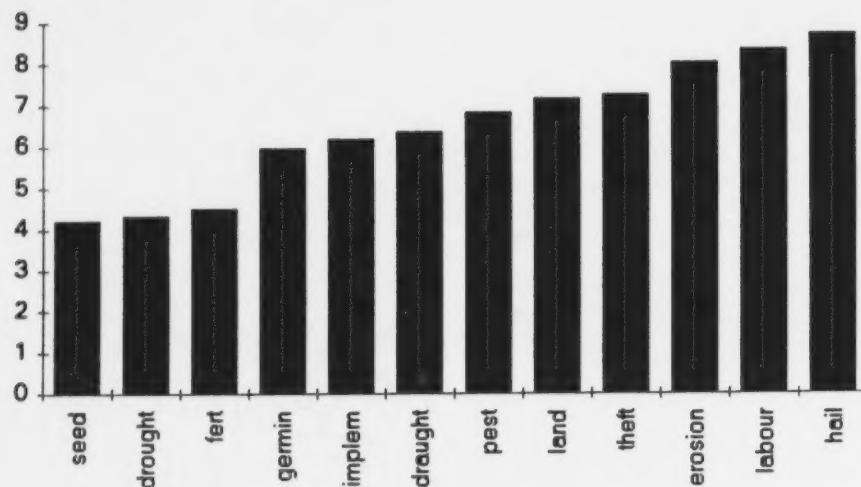


Figure 4.1. Relative ranking (1-12) of constraints to production by mean score

where,	
seed =	access to hybrid seed or ability to purchase it
drought =	damage caused by drought
fert =	access to fertilizer or ability to purchase it
germin =	poor germination
implem =	difficulty in accessing or buying own farm capital
draught =	difficulty in accessing or buying own draught or oxen team
pest =	damage caused by pests
land =	land security relating to issues of ownership
theft =	damage to crops primarily by illegal grazing of animals
erosion =	damage to land through erosion or soil degradation
labour =	labour constraints in the production process
hail =	damage caused by hail

These findings suggest that farmers rate labour scarcity as a relatively minor problem. The more constraining variables, such as fertilizer and farm implements, suggests that their correlation to output productivity may be high. One further observation of interest is the low scoring of the erosion (or land degradation) constraint which coincides with the findings of John Gay (1984) mentioned in chapter two.

Labour (per household) has been quantified by six different means, the first three as follows: (1) RLAB - an estimated productive labour measurement (see appendix three for calculation procedure), (2) FLAB - a count of all on-farm working family members (excludes sick family members who do not engage in farm work), and (3) PLAB - a simple count of all on and off-farm family members. Three other variables are calculated by dividing each of the above variables by the number of fields cultivated by the family (RFLAB, FFLAB, PFLAB). The number of variables used to capture the actual labour supply is justified given uncertainty with regards to the nature of labour application that exists: Does productivity differ between family members? Do off-farm workers return home during peak harvest times? Can the application of labour to a field (in spite of the inadequacies of this approach: fields vary in size) be considered as a reasonable proxy for a labour per land unit measurement?

4.3.2. FARM CAPITAL

Farm capital includes items such as plows, planters, cultivators, harrows, hoes, hauling carts, and oxen teams (or their cattle equivalent; see appendix three for calculation procedure). A stock variable for farm capitalization is applied in the regression analysis that follows for two reasons: one, the ease of collecting such data (*vis-à-vis* other flow variables mentioned earlier), and secondly, the consideration that the *accessibility* of farm capital may be the critical issue. This point relates, in part, to comments from a Sechaba Consultants report (Judy Gay and Green, 1991): farmers without capital goods often wait for others to finish working on their fields before they

can access, for variable rates, the needed equipment. If farm capital were valued at the average rental rate, then most farm operations would be accorded a near equal level of farm capitalization (with the possible exclusion of farmers who hire a tractor operator to plow their fields). The importance of timing in farming an arid, drought prone environment such as Lesotho's, where frosts can bring a prompt end to the growing season, should be stressed (Baker and Eicher, 1992). The value of farm capital can then provide a proxy measure of the "timely" accessibility of farm inputs.

In this study, two different capital stock measures are used: one reflecting the value of all mechanical inputs, the other includes mechanical inputs and draught power. If the family in question owns two oxen, or four cattle, then they are considered to have full access to the necessary draught power for their farming requirements. Any draught power above this value does not incrementally increase the capital stock measurement.

A fertilizer variable, the only flow variable applied in the subsequent analysis, is included in part because of its ease of collection and also the emphasis this study places on soil quality. As most fertilizers contain phosphorus and potassium, chemicals included in a number of applied soil quality variables, there is a potential for multicollinearity to occur if detectable levels of fertilizer are present in the soil when sampling is undertaken. To avoid this problem, an attempt was made to take soil samples before sowing and fertilizer application commenced.

4.3.3. FIELD SLOPE

The effects of field slope on agricultural production was hypothesized to be negative. In Lesotho, a country dominated by mountains and rolling hills, field slope may play a significant role in influencing output levels. The consideration that, as a result of human pressure on land resources, many newly cultivated fields are located on steeper slopes is validated by close examination of the countryside in Lesotho. This raises a statistical problem for cross-sectional data: if the duration of time cultivation has been practised on steeper slopes is considerably less than it has been, for example, in valley floors, then fields on steep inclines may be associated with inappropriately high levels of soil quality. Output values may be high during the first year or two, but taper off quickly thereafter (Harrison, 1987).

4.3.4. SOIL QUALITY

Six different measures of soil quality used in the subsequent analysis are presented below.

Table 4.2. Soil quality variables as applied in production analysis

VAR. NAME †	COMPOSITION
SOIL1	SOIL DEPTH (ALONE)
SOIL2	ORGANIC MATTER + PHOSPHORUS + POTASSIUM LEVELS ‡
SOIL3	DEPTH• (ORGANIC MATTER + PHOSPHORUS + POTASSIUM LEVELS)
SOIL4	DEPTH• (PHOSPHORUS + POTASSIUM LEVELS)
SOIL5	DEPTH• (PHOSPHORUS + POTASSIUM LEVELS)*PH LEVEL
SOIL6	DEPTH• (ORGANIC MATTER + PHOSPHORUS + POTASSIUM LEVELS)*PH LEVEL

† all soil quality variables are subsequently converted into log form; variables beginning with an "L" represent the log value of the original variable: e.g. LSOIL1 is the log of SOIL1.

‡ soil nutrients phosphorus and potassium as well as organic matter appear as normalized variables in all soil quality variables.

The components of soil quality were discussed in chapter two. The SOIL1 (soil depth) variable is included in the analysis primarily because of its ease of collection and its frequent application in economic literature (see for e.g. McConnell, 1983; Lerohl et al., 1990). As the SOIL2 variable has no reference to soil depth, the importance of its previous and subsequent inclusion can be assessed. The remaining soil quality variables utilize normalized values for organic matter, phosphorus, and potassium in order to apply a proportionate representation for each.

With the exception of SOIL1 and SOIL2, the rationale behind the soil quality variables is that soil depth multiplied by concentration level of soil nutrients provides a representation of the absolute amounts of phosphorus and potassium contained in the soil. The importance of the rooting depth is also subsumed into all but one (SOIL2) of the soil quality variables. Each variable is formulated to provide an anticipated correlation with output productivity with one possible qualification: organic matter content.

As is the case with agricultural production, land is exposed to erosive agents that can leach (vertical erosion) or transport soil and surface nutrients away from cropland. The greatest land degradation problems in Lesotho are associated with water and wind erosion of topsoil, where the bulk of organic matter is resident (Nobe and Seckler, 1979). Cultivated lands, where soils are exposed to the full impact of such erosive agents, are anticipated to have relatively low levels of organic matter content (generally < 2% in data set) with intensely farmed lands at the low end of the spectrum. As a result, organic matter may appear to possess an ambiguous or possibly

negative relationship with output. Its hidden value could be revealed through time series analysis. In the case of phosphorus and potassium, which are generally less mobile in soils, some would also be lost by the removal of topsoil, but as they are originally derived from parent material, the lost proportion may be less than it is for organic matter.

Soil depth and pH levels are represented by their true values. As pH levels rise, soil acidity decreases, implying more nutrient availability for plant uptake. The product of a basic soil quality measurement and the respective pH value then serves to establish a new variable which reflects the deleterious impact of acidity on crop production in Lesotho.

4.4. PRODUCTION ANALYSIS

4.4.1. PRODUCTIVITY

The mean value of production per hectare (productivity) and other descriptive statistics for the variable are provided below. Output is measured in terms of Lesotho's currency, the loti (plural: maloti), which is pegged to the South African Rand. The loti was valued at approximately \$0.42 Canadian in 1993, when this study was undertaken. Output prices, provided by the Ministry of Agriculture (Lesotho), represent established market values for 1992 (see appendix five). (All descriptive statistics and regression analyses presented below are drawn from a data set of 85 observations. The *SHAZAM Econometrics Computer Program*, Version 7.0 [White

1993] was used for statistical and regression analysis throughout this chapter, excepting cross-tabulations in section 4.9.)

Table 4.3. Basic statistics for productivity measure (PRODUCT = output value per hectare).

NAME	MEAN	ST. DEV	VARIANCE	MINIMUM	MAXIMUM
PRODUCT	848.26	865.47	749040.0	0.71065	3790.9

4.3.2. LABOUR SUPPLY

As mentioned, six labour supply measures have been specified:

Table 4.4.a. Basic statistics for six labour supply variables

NAME	MEAN	ST. DEV	VARIANCE	MIN	MAX
RLAB	4.2108	1.7502	3.0634	1.0000	10.2000
PLAB	6.6000	2.4650	6.0762	2.0000	16.0000
FLAB	4.5882	1.8917	3.5784	1.0000	10.0000
RFLAB	2.6979	1.6412	2.6936	0.6200	10.0450
PFLAB	4.2561	2.4902	6.2011	1.0000	16.0000
FFLAB	2.9271	1.7693	3.1303	0.6667	10.0000

where,

RLAB	=	productive labour estimate (see appendix for calculation),
FLAB	=	the number of working people on the household farm,
PLAB	=	total number of family members present or absent from farm,
RFLAB	=	productive labour measure divided by number of fields farmed by family,
PFLAB	=	farm workers per family field divided by number of fields farmed by family,
FFLAB	=	the log of family members divided by number of fields farmed by family.

The values in the correlation coefficient table below suggest that labour supply and output productivity are not significantly related. A strong collinear relationship between labour and another explanatory variable, however, may adversely affect the correlation coefficient of labour and output productivity.

Table 4.4.b. Correlation coefficient table of productivity and six measures of labour stock.

RLAB	-0.0619
PLAB	-0.0166
FLAB	0.0221
RFLAB	-0.0976
PFLAB	-0.0829
FFLAB	-0.0494
	PRODV

The logarithmic correlation matrix appears as follows:

Table 4.4.c. Correlation coefficient table of log of productivity and six measures of labour stock.

LRLAB	-0.0925
LPLAB	-0.0766
LFLAB	-0.0114
LRFLAB	-0.1050
LPFLAB	-0.0879
LPFLAB	-0.0433
	LPRODUCT

* above variables are simply log form of variables mentioned in table 4.4.b.

The negative correlation between the log of productive on-farm labour (LRFLAB) and product per hectare (LPRODV) is the opposite of the anticipated sign. Regressing labour on all other explanatory variables revealed that no significant relationships, discounting the notion that collinearity is responsible for the sign of the labour variable. The negative sign may indicate that households with highly productive family members apply their labour away from their own fields. It may also indicate an incorrect specification of Irrespective of possible explanations for this occurrence, the negative relationship suggests that a labour supply variable is inappropriate for the production analysis that follows (Sankhayan, 1988).

4.3.3. CAPITAL

Some descriptive statistics for the two capital stock variables mentioned earlier are presented below.

Table 4.5.a. Basic statistics for fixed capital variables.

NAME	MEAN	ST. DEV	VARIANCE	MIN	MAX
CAPMECH	1522.50	1532.2	2347700.0	1.0000	4770.0
CAPME2	4638000.0	5925300.0	0.35109E+14	1.0000	22753000.0
CAPMOX	2899.0	2233.2	4987300.0	1.0000	7170.0
CAPMO2	13333000.0	14016000.0	0.19645E+15	1.0000	51409000.0

where,

CAPMECH	=	value of mechanical farm capital (see appendix five),
CAPMOX	=	value of mechanical farm capital and draught power (oxen or cattle equivalent).
CAPME2	=	square of CAPMECH
CAPMO2	=	square of CAPMOX

A correlation coefficient table for the same variables is displayed below in standard and log form.

Table 4.5.b. Correlation coefficient table of productivity (log of productivity) and capital variable (log of capital).

CAPMECH	0.0675	LCAPME	0.0916
CAPME2	0.0792	LCAPME2	0.0907
CAPMOX	0.1175	LCAPMO	0.1539
CAPMO2	0.0894	LCAPMO2	0.1649
	PRODUCT		LPRODUCT

where "L" denotes natural logarithmic representation and LCAPME2 and LCAPMO2 represent the squared values of LCAPME and LCAPMO respectively.

The anticipated sign for the capital variable corresponds to the above results, with LCAPMO and LCAPMO2 (the square of LCAPMO) displaying the strongest correlation to output productivity. Results from statistical analysis of the capital flow variable, fertilizer, are as follows:

Table 4.5.c. Basic statistics for fertilizer variable.

NAME	MEAN	ST. DEV	VARIANCE	MIN	MAX
FERTPR1	148.50	129.13	16674.00	0.9967	714.84
FERTPR2	38531.00	70402.00	0.49564E+10	0.9933	51100.00

where,

FERTPR1 = kilograms application of fertilizer,

FERTPR2 = square of log of application.

The correlation coefficients below suggest a strong relationship between fertilizer application and output.

Table 4.5.d. Correlation coefficient table of fertilizer and productivity variables.

FERTPR1	0.3513	LFERTPR1	0.2556
FERTPR2	0.2537	LFERTPR2	0.2632
	PRODUCT		LPRODUCT

where,

LFERTPR1 = log of fertilizer application,

LFERTPR2 = square of log of application.

4.3.4. SLOPE MEASUREMENTS

Statistics describing the results of slope assessment (percent) using an Abney level are as follows:

Table 4.6.a. Basic statistics of slope variable.

NAME	MEAN	ST. DEV	VARIANCE	MIN	MAX
SLOEDIT	8.3000	3.6032	12.983	1.0000	18.000
SLOED2	81.721	68.698	4719.4	1.0000	324.00

where,

SLOEDIT = general slope of analyzed field

SLOED2 = square of SLOEDIT

In standard form, slope does not appear to be significantly correlated to agricultural productivity, however, the square of the log form (LSLOED2) seems to bear moderate correlation.

Table 4.6.b. Correlation coefficient table of slope and productivity variables.

SLOEDIT	-0.0046	LSLOED	-0.0851
SLOED2	-0.0003	LSLOED2	-0.1486
	PRODUCT		LPRODUCT

where,

LSLOED = log of SLOEDIT

LSLOED2 = square of LSLOED

4.3.5. SOIL QUALITY

The relationship between soil quality and agricultural output has been outlined in chapter two. Six soil quality variables were defined earlier in this section. The following tables provide the outcome of statistical analysis for the soil variables.

Table 4.7.a. Basic statistics of soil quality variables.

NAME	MEAN	ST. DEV	VARIANCE	MINIMUM	MAXIMUM
SOIL1	28.6350	8.8369	78.0920	15.0000	60.0000
SOIL2	3.0000	1.2248	1.5002	0.6747	6.2715
SOIL3	85.5000	42.5970	1814.5000	16.8660	193.4900
SOIL4	56.5670	33.4210	1116.9000	14.5340	160.9700
SOIL5	284.1800	175.4000	30763.0000	82.5860	837.4100
SOIL6	424.8400	212.2900	45068.0000	82.6450	985.7700

Table 4.7.b. Correlation coefficient table for soil and productivity variables.

SOIL1	0.2092	LSOIL1	0.2659
SOIL2	0.1553	LSOIL2	0.1118
SOIL3	0.2315	LSOIL3	0.2475
SOIL4	0.3582	LSOIL4	0.3884
SOIL5	0.3745	LSOIL5	0.3839
SOIL6	0.2705	LSOIL6	0.2564
	PRODUCT		LPRODUCT

In this case, the difference between the standard and the natural log form of the variables is not that significant. Owing to the econometric specification of the production models that follows, both log and standard number formats are required. Further analysis of soil quality will be restricted to the soil variables whose correlation coefficient with agricultural productivity is greater than 0.30 with the exception of SOIL1, which will be applied for its ease of collection and frequent referencing in economic-related literature.

The R^2 value for a simple regression (one variable) is the square of the correlation coefficient for the single regressor variable in question. The R^2 values for simple regressions involving SOIL1, SOIL4, AND SOIL5 as explanatory variables and output productivity as the dependent variable are therefore 0.0438, 0.1283, and 0.1403 respectively. For LSOIL1, LSOIL4, AND LSOIL5 regressed on the log of productivity (LPRODUCT) the R^2 values are 0.0707, 0.1509, and 0.1474 respectively. The low significance associated with soil variables (SOIL2, SOIL3, AND SOIL6) which incorporate organic matter content, supports earlier conjecture that higher intensity farming practices may, in cross-sectional analysis, be associated with lower levels of organic matter in cropland soils.

4.4. PRODUCTION ANALYSIS

A set of production variables – capital stock, fertilizer application, slope, and soil quality – all reasonably correlated with the output productivity, has been established. The analysis now turns to assessing how well four functions (linear,

quadratic, Cobb-Douglas, and translog) fit the data collected for this study. Once an appropriate function is established, attention will be focused on two problems that can affect the validity of regression analysis performed on a cross-sectional data base, namely, multicollinearity and heteroskedasticity.

For each functional form, the generic estimating format is written above output generated by running the SHAZAM (White, 1993) Econometrics Computer Program. Explanations of certain statistics are provided below for clarity. Discussion of output results are reserved for section 4.5.

4.4.1. LINEAR PRODUCTION FUNCTION

ESTIMATING FORMAT: $y = \beta_0 + \beta_1 x_1 + \dots + \beta_k x_k + \varepsilon$

A. SOIL QUALITY MEASUREMENT: SOIL1

Table 4.8.a. Linear model regression output (SOIL1): general statistics

DEPENDENT VARIABLE	MEAN OF DEP. VAR.	R ²	R ² ADJ.	FSTAT (RSS; MEAN)	LEVEL OF SIG. (F _{1,98})	VAR. OF ESTIMATED σ^2
PRODUCTIVITY	848.26	0.1926	0.1523	4.772	0.01	634,980

Table 4.8.b. Linear model regression output (SOIL1): coefficient statistics

VARIABLE	EST. COEFF.	STAND. ERROR	T-RATIO 80 df	P-VALUE	PART. CORR.	STAND. COEFF.	SIG. LEVEL
CAPMOX	.0201	.03943	0.5086	0.6120	0.0570	0.0517	
FERTPR1	2.5403	0.6837	3.7150	0.0000	0.3840	0.3790	0.001
SLOEDIT	-7.1185	24.2300	-0.2938	0.7700	-0.0330	-0.0296	
SOIL1	24.9500	10.0300	2.4860	0.0150	0.2680	0.2548	0.020
CONSTANT	-242.4800	375.600	-0.6455	0.5200	-0.0720	0.0000	

Where,

CAPMOX = value of capital including draught power
 FERTPR1 = fertilizer application per hectare.
 SLOEDIT = general slope of analyzed field
 SOIL1 = soil depth

Abbreviated output statistics printed above are defined as follows (White, 1993):

EST. COEFF. = ESTIMATED COEFFICIENT (β_k)

STAND. ERROR	=	STANDARD ERROR (SE_k) = $\sqrt{V(\beta_k)}$
T-RATIO	=	T-STATISTIC $t_k = \beta_k / SE_k$
P-VALUE	=	This statistic relates to the cumulative density function of the t-distribution
PART. COEFF.	=	PARTIAL CORRELATION = $t_k / (\sqrt{t_k^2 + N - K})$
STAND. COEFF.	=	STANDARDIZED COEFFICIENT = $(\beta_k)^* = \beta_k (\sigma_{Yk} / \sigma_X)$
ELAS. AT MEANS	=	ELASTICITY AT MEAN VALUES = E_k $= \beta_k (X_{(\text{mean})k} / Y_{(\text{mean})})$
SIG. LEVEL	=	LEVEL OF SIGNIFICANCE OF T STATISTIC

B. SOIL QUALITY MEASUREMENT: SOIL4

Table 4.9.a. Linear model regression output (SOIL4): general statistics

DEPENDENT VARIABLE	MEAN OF DEP. VAR.	R ²	R ² ADJ.	FSTAT (RSS; MEAN)	LEVEL OF SIG. (F _{5,99})	VAR. OF ESTIMATED σ^2
PRODUCTIVITY	848.26	0.2366	0.1984	6.197	0.01	600,440.0

Table 4.9.b. Linear model regression output (SOIL4): coefficient statistics

VARIABLE	EST. COEFF.	STAND. ERROR	T-RATIO 80 df	P-VALUE	PART. CORR.	STAND. COEFF.	SIG LEVEL
CAPMOX	.03711	0.0381	0.9745	0.3330	0.108	0.0958	
FERTPR1	2.0349	0.6629	3.070	0.0030	0.325	0.3036	0.005
SLOEDIT	-10.7640	23.6200	-0.4557	0.6500	-0.051	-0.0448	
SOIL4	8.5645	2.5660	3.338	0.0010	0.350	0.3307	0.002
CONSTANT	43.3600	279.2000	0.1553	0.8770	0.017	0.0000	

C. SOIL QUALITY MEASUREMENT: SOIL5

Table 4.9.c. Linear model regression output (SOIL5): general statistics

DEPENDENT VARIABLE	MEAN OF DEP. VAR.	R ²	R ² ADJ.	FSTAT (RSS; MEAN)	LEVEL OF SIG. (F _{5,99})	VAR. OF ESTIMATED σ^2
PRODUCTIVITY	848.26	0.2441	0.2063	6.457	0.01	594,540.0

Table 4.9.d. Linear model regression output (SOIL5): coefficient statistics

VARIABLE	EST. COEFF.	STAND. ERROR	T-RATIO 80 df	P-VALUE	PART. CORR.	STAND. COEFF.	SIG LEVEL
CAPMOX	.0412	.0380	1.0850	0.2810	0.1200	0.1062	
FERTPR1	1.9569	0.6623	2.9550	0.0040	0.3140	0.2920	0.005
SLOEDIT	-11.0500	23.5100	-0.4701	0.6400	-0.0520	-0.0460	
SOIL5	1.6971	0.4890	3.4700	0.0010	0.3620	0.3439	0.001
CONSTANT	47.7560	275.7000	0.1732	0.8630	0.0190	0.0000	

4.4.2. QUADRATIC PRODUCTION FUNCTION

ESTIMATING FORMAT: $y = \beta_0 + \beta_1 \Sigma x_i + \beta_2 \Sigma x_i^2 + \beta_{ij} \Sigma x_i x_j + \varepsilon$ (for $i, j = 1$ to n)

SOIL QUALITY MEASUREMENT: SOIL5 AND DERIVATIVE VALUES

Table 4.10.a Quadratic model regression output (SOIL5): general statistics

DEPENDENT VARIABLE	MEAN OF DEP. VAR.	R ²	R ² ADJ.	FSTAT (RSS; MEAN)	LEVEL OF SIG. (F _(14,71))	VAR. OF ESTIMATED σ^2
PRODUCTIVITY	848.26	0.3608	0.2329	2.882	0.01	574,550.0

Table 4.10.b. Quadratic model regression output (SOIL5): coefficient statistics

VARIABLE	EST. COEFF.	STAND. ERROR	T-RATIO 70 df	P-VALUE	PART. CORR.	STAND. COEFF.	SIG. LEVEL
CAPMOX	0.1338	0.1719	0.7785	0.439	0.0930	0.3452	
CAPMO2	-0.0001	0.00002	-1.8890	0.063	-0.2200	-0.7046	0.10
FERTPR1	-1.3689	2.8900	-0.4737	0.637	-0.0570	-0.2042	
FERTPR2	-0.0041	0.0034	-1.2080	0.231	-0.1430	-0.3317	
SLOEDIT	-179.9900	102.1000	-1.7630	0.082	-0.2060	-0.7493	0.10
SLOED2	5.0622	4.9980	1.0130	0.315	0.1200	0.4018	
SOIL5	-0.2746	3.0640	-0.0896	0.929	-0.0110	-0.0556	
SOIL52	0.0001	0.0025	0.0198	0.984	0.0020	0.0085	
CF	0.0005	0.0003	1.3130	0.193	0.1550	0.3552	
CS	0.0099	0.0109	0.9129	0.364	0.1080	0.2602	
C5	0.0001	0.0002	0.4166	0.678	0.0500	0.1003	
SF	0.1669	0.1952	0.8549	0.396	0.1020	0.2670	
S5	0.0910	0.2130	0.4273	0.670	0.0510	0.1965	
F5	0.0073	0.0035	2.0710	0.042	0.2400	0.4989	0.05
CONSTANT	1261.0000	782.3000	1.6120	0.111	0.1890	0.0000	

Where,

CAPMO2	=	square of CAPMOX
FERTPR2	=	square of FERTPR1
SLOED2	=	square of SLOEDIT
SOIL52	=	square of SOIL5
CF	=	CAPMOX • FERTPR1
CS	=	CAPMOX • SLOEDIT
C5	=	CAPMOX • SOIL5
SF	=	SLOEDIT • FERTPR1
S5	=	SLOEDIT • SOIL5
F5	=	FERTPR1 • SOIL5.

4.4.3. COBB-DOUGLAS PRODUCTION FUNCTION

ESTIMATING FORMAT: $\ln(y) = \beta_0 + \beta_1 \ln(x_1) + \dots + \beta_i \ln(x_i) + \varepsilon$

A. SOIL QUALITY MEASUREMENT: NATURAL LOG VALUE OF SOIL1

Table 4.11.a. Cobb-Douglas model regression output (SOIL1): general statistics

DEPENDENT VARIABLE	MEAN OF DEP. VAR.	R ²	R ² ADJ.	FSTAT (RSS; MEAN)	LEVEL OF SIG. (F _{4,31})	VAR. OF ESTIMATED σ^2
LOG OF PRODUCTIVITY	5.5506	0.1895	0.1490	4.667	0.01	4.3863

Table 4.11.b. Cobb-Douglas model regression output (SOIL1): coefficient statistics

VARIABLE	EST. COEFF.	STAND. ERROR	T-RATIO 80 df	P-VALUE	PART. CORR.	STAND. COEFF.	SIG LEVEL
LCAPMO2	0.0129	0.0096	1.3380	0.185	0.148	0.1361	
LFERTPR1	0.3475	0.1436	2.4200	0.018	0.261	0.2497	0.05
LSLOED2	-0.1825	0.1275	-1.4310	0.156	-0.158	-0.1462	
LSOIL1	2.3749	0.7868	3.0190	0.003	0.320	0.3066	0.005
CONSTANT	-3.7261	2.7980	-1.3320	0.187	-0.147	0.0000	

B. SOIL QUALITY MEASUREMENT: NATURAL LOG VALUE OF SOIL4

Table 4.11.c. Cobb-Douglas model regression output (SOIL4): general statistics

DEPENDENT VARIABLE	MEAN OF DEP. VAR.	R ²	R ² ADJ.	FSTAT (RSS; MEAN)	LEVEL OF SIG. (F _{4,31})	VAR. OF ESTIMATED σ^2
LOG OF PRODUCTIVITY	5.5506	0.2776	0.2415	7.687	0.01	3.9093

Table 4.11.d. Cobb-Douglas model regression output (SOIL4): coefficient Statistics

VARIABLE	EST. COEFF.	STAND. ERROR	T-RATIO 80 df	P-VALUE	PART. CORR.	STAND. COEFF.	SIG LEVEL
LCAPMO2	0.0170	0.0091	1.858	0.067	0.203	0.1792	0.100
LFERTPR1	0.2684	0.1352	1.986	0.050	0.217	0.1929	0.050
LSLOED2	-0.2542	0.1222	-2.081	0.041	-0.227	-0.2036	0.050
LSOIL4	1.8162	0.4063	4.470	0.000	0.447	0.4339	0.001
CONSTANT	-2.4873	1.7590	-1.414	0.161	-0.156	0.0000	

C. SOIL QUALITY MEASUREMENT: NATURAL LOG VALUE OF SOIL5

Table 4.11.e. Cobb-Douglas model regression output (SOIL5): general statistics

DEPENDENT VARIABLE	MEAN OF DEP. VAR.	R ²	R ² ADJ.	FSTAT (RSS; MEAN)	LEVEL OF SIG. (F _{4,81})	VAR. OF ESTIMATED σ^2
LOG OF PRODUCTIVITY	5.5506	0.2747	0.2384	7.574	0.01	3.9253

Table 4.11.f. Cobb-Douglas model regression output (SOIL5): coefficient statistics

VARIABLE	EST. COEFF.	STAND. ERROR	T-RATIO 80 df	P-VALUE	PART. CORR.	STAND. COEFF.	SIG. LEVEL
LCAPMO2	0.0176	0.0092	1.919	0.059	0.210	0.1858	0.10
LFERTPR1	0.2644	0.1355	1.951	0.055	0.213	0.1900	0.10
LSLOED2	-0.2526	0.1224	-2.064	0.042	-0.225	-0.2023	0.05
LSOIL5	1.7444	0.3943	4.424	0.000	0.443	0.4309	0.001
CONSTANT	-5.0269	2.2810	-2.204	0.030	-0.239	0.0000	0.05

4.4.4. TRANSLOG PRODUCTION FUNCTION

ESTIMATING FORMAT:

$$\ln(y) = \beta_0 + \beta_1 \ln(x_1) + \beta_2 \ln(x_2) \dots + \beta_{ij} \ln(x_i) \ln(x_j) + \varepsilon \quad (\text{for } i, j = 1 \text{ to } n)$$

SOIL QUALITY MEASUREMENT: NATURAL LOG VALUE OF SOIL5 AND DERIVATIVES

Table 4.12.a. Translog model regression output (SOIL5): general statistics

DEPENDENT VARIABLE	MEAN OF DEP. VAR.	R ²	R ² ADJ.	FSTAT (RSS; MEAN)	LEVEL OF SIG. (F _{4,81})	VAR. OF ESTIMATED σ^2
LOG OF PRODUCTIVITY	5.5506	0.3717	0.2460	2.957	0.01	3.8863

Table 4.12.b. Translog model regression output (SOIL5): coefficient statistics

VARIABLE	EST. COEFF.	STAND. ERROR	T-RATIO 70 df	P-VALUE	PART. CORR.	STAND. COEFF.	SIG LEVEL
LCAPMO	0.93227	1.316	0.7086	0.481	0.084	0.8530	
LCAPMO2	0.033662	0.05831	0.5772	0.566	0.069	0.3554	
LFERTPR1	-1.0970	1.501	-0.7309	0.467	-0.087	-0.7884	
LFERTPR2	0.037823	0.08537	0.4430	0.659	0.053	0.1718	
LSLOED	-10.633	5.814	-1.829	0.072	-0.214	-2.5000	0.10
LSLOED2	-1.2352	0.5101	-2.422	0.018	-0.278	-0.9892	0.02
LSOIL5	5.0619	7.975	0.6347	0.528	0.076	1.2503	
LSOIL52	-0.40118	0.6723	-0.5967	0.553	-0.071	-1.1061	
LCF	0.13822	0.07478	1.848	0.069	0.216	0.9121	0.10
LCS	0.25933	0.2683	0.9667	0.337	0.115	0.6611	
LC5	-0.39312	0.2292	-1.715	0.091	-0.201	-2.0606	
LFS	0.24409	0.2902	0.8412	0.403	0.100	0.4401	
LF5	-0.069489	0.2331	-0.2981	0.767	-0.036	-0.2913	
LS5	2.0850	1.160	1.798	0.077	0.210	2.9659	
CONSTANT	-4.1325	25.53	-0.1619	0.872	-0.019	0.0000	

Where,

LCAPMO2	=	square of LCAPMO
LFERTPR2	=	square of LFERTPR1
LSLOED2	=	square of LSLOED
LSOIL52	=	square of LSOIL5
LCF	=	LCAPMO • LFERTPR1
LCS	=	LCAPMO • LSLOED
LC5	=	LCAPMO • LSOIL5
LFS	=	LFERTPR1 • LSLOED
LF5	=	LFERTPR1 • LSOIL5
LS5	=	LSLOED • LSOIL5

4.5. MODEL SELECTION

The Cobb-Douglas appears to provide the best fitting functional form. As expressed in the previous chapter, the Cobb-Douglas is bound to either decreasing, constant or increasing returns to scale. Output from model 4.11.f. would suggest that production is bound to increasing returns to scale, as the coefficient of the soil quality variable, or the factor elasticity, is greater than one (1.74). The first Cobb-Douglas function which employed LSOIL1 had a two variables and a constant that were not significant at the 0.10 level, coupled with a relatively low R^2 value. While the Cobb-Douglas function

that applied the LSOIL4 variable (Model 4.4.3.b.) has a slightly higher adjusted R^2 value than the function employing the LSOIL5 variable (Model 4.4.3.c.), the models are non-nested and therefore cannot, in general, be compared in such a fashion. The t-statistic for the constant in model 4.4.3.b. is not significant at the 0.10 level, while all variables in Model 4.4.3.c. are significant at the 10% level, including the constant. A reasonably high R^2 value also exists in 4.4.3.c. considering the cross-sectional, non-controlled nature of the data set. Below, the three Cobb-Douglas estimating equations (4.4.3.A through 4.4.3.c.) are subject to some diagnostic tests for possible multicollinear and heteroskedastic tendencies.

4.6. DIAGNOSTICS

4.6.1 MULTICOLLINEARITY

If any of the variables employed in the regression analysis are highly correlated with the other variables, then the value of our model is discounted: t-statistics are diminished and individual coefficients are unreliable (Ramanathan, 1992). This concern is well-founded given the number of variables describing soil and land quality and the intuitive potential for collinear movements among production variables.

Table 4.13 Correlation matrix for explanatory variables.

LFERTPR1		1.0000					
LCAPMO2	a	0.1359	1.0000				
LSLOED2	b	-0.1407	0.0328	1.0000			
LSOIL1	c	-0.1083	-0.0010	0.0922	1.0000		
LSOIL4		0.0223	-0.0780	d	0.1758	0.4929	1.0000
LSOIL5		0.0275	-0.0930	e	0.1726	0.4414	0.9831
	LFERTPR1	LCAPMO2	LSLOED2	LSOIL1	LSOIL4	LSOIL5	

In the correlation matrix of explanatory variables presented above, the following concerns and points of interest arise:

- The relatively high correlation between fertilizer application per hectare and capitalization levels demonstrates that fixed and variable capital inputs are moderately correlated (box a).
- That less fertilizer is applied on steeper slopes, apparent through the negative correlation coefficient in box b could be intuited, however a third variable, wealth, may influence this relationship. If wealthier families farm in the flatter and more fertile valley floors (Dr. J. Machobane, personal communication, 1993; Blaikie, 1985), and if wealth is associated with greater levels of capitalization, then wealth is, in part, responsible for the apparent correlation effect (see table 4.15. below).
- Soil depth is moderately negative in correlation with fertilizer application, suggesting that the two variables may be substitutes (box c). An alternate explanation is that households that farm intensively (heavy application of fixed and variable capital) may be eroding soils more than minimal-input farmers.
- The positive correlation between the slope variable and SOIL4 and SOIL5 supports the earlier suggestion that recently cultivated fields on relatively steep slopes are less degraded than fields in valley floors where cultivation has been taking place for a century or more. The result may be a temporarily high level of soil quality for the first few years of cultivation, until the deleterious effects of water, and to a lesser extent, wind erosion make the soil unproductive. Shifting agricultural practices on steep slopes in Lesotho's countryside can readily be observed.

The following correlation matrix examines the relationships between components of soil quality and fertilizer application.

Table 4.14. Correlation matrix for components of soil quality and fertilizer application.

FERTPR1	1.0000				
P	0.16421 a	1.0000			
K	0.15775 b	0.14995 c	1.0000		
OM	-0.73832E-01	-0.24812 d	0.82721E-01	1.0000	
PH	0.58299E-01	0.94745E-01	0.33324 e	-0.21337 f	1.0000
	FERTPR1	P	K	OM	PH

P = Phosphorus
 K = Potassium
 OM = Organic Matter
 PH = pH levels (acidity-alkalinity level)

The positive relationship exhibited in boxes a and b suggests that during soil sampling, some residual amounts of phosphorus and potassium from previous fertilizer applications were collected. Other correlation coefficients of interest reveal surprisingly negative relationships between organic matter and P and between organic matter and pH levels. Again, these issues may be more appropriately scrutinized through time series analysis.

Correlation coefficients presented in the table below suggest that, contrary to earlier speculation, there is no significant relationship between field slope and wealth. Wealth, however, is associated with capitalization (farm capital is itself a component of family wealth; see appendix five) and fertilizer application (boxes b and a respectively).

Table 4.15. Correlation matrix of slope, capital variables and wealth.

FERTPR1	1.0000			
CAPMOX	0.10068	1.0000		
WEALTH	0.15754 a	0.59753 b	1.0000	
SLOEDIT	0.10401E-01	-0.11641E-01	-0.95600E-01	1.0000
	FERTPR1	CAPMOX	WEALTH	SLOEDIT

The hypothesis that fertilizer application or slope significantly affect soil quality, and therefore introduce multicollinearity into the model, can be tested by regressing these explanatory variables on one another. Regression output for testing these relationships below do not show any signs of strong multicollinearity (at 0.10 level or less). A collinear relationship does exist, however, between both soil quality variables and slope at the 0.20 level.

Table 4.16. Regression tests for multicollinear tendencies

Regression	Dep. Soil Variable	Explanatory Variable	d.f.	T-Ratio	α (2 tail)	Collinearity (☒ ☒)
I.	LSOIL4	LFERTPR1	83	0.203	(0.80)	☒
II.	LSOIL4	LSLOED2	83	1.627	(0.20)	☒
III.	LSOIL5	LFERTPR1	83	0.251	(0.80)	☒
IV.	LSOIL5	LSLOED2	83	1.596	(0.20)	☒

Where ☒ indicates that multicollinearity is not present at an alpha level of 0.10 or less. See appendix four for more complete information.

The joint hypothesis that capital and slope (LCAPMO2 and LSLOED2) have no effect on fertilizer application (LFERTPR1) cannot be rejected at the 5% level ($F_{2,82} = 1.688 < F_{2,82}^c \approx 3.10$). The joint hypothesis that fertilizer application, capital, and slope (LFERTPR1, LCAPMO2, and LSLOED2) have no effect on soil quality (SOIL4 or SOIL5) also cannot be rejected at the 5% level ($F_{3,81} = 1.170 < F_{3,81}^c \approx 2.72$ for SOIL4 and $F_{3,81} = 1.243 < F_{3,81}^c \approx 2.72$ for SOIL5).

At this point, it appears reasonable to discard LSOIL4 from the production modelling exercise in favour of the LSOIL5 variable. The constant in the LSOIL4 variable is insignificant, generating uncertainty where the values of the model-derived marginal revenue products are concerned. Considering the potential for conservation projects or researchers to track a composite variable using simple soil analysis techniques, in the case of Lesotho, SOIL5 appears to be the best choice. While maintaining a high level of significance, it captures the importance of:

- soil depth: defines the rooting depth and, when multiplied by potassium and phosphorus concentration levels, reflects the total amount of these chemical nutrients available to plants.
- potassium: essential macronutrient (see chapter two) related to the parent material and leaching properties of a soil
- phosphorus: essential macronutrient related to parent material and organic matter in the soil (although this is not apparent in the data set); positively correlated with nitrogen levels

- pH level determines whether certain soil nutrients are available or not (as mentioned chapter two).

4.6.2. HETEROSKEDASTICITY

Heteroskedasticity occurs where the OLS assumption that the residuals are identically distributed with mean zero and equal variance σ^2 across the sample is violated (see section 3.2). In the analysis that follows, heteroskedasticity is considered for: differing levels of wealth and education, gender of farm management, and different farming systems. Before testing for heteroskedasticity, rationale for the alternate hypothesis is proposed. Model 4.11.f. (Cobb-Douglas Model with LSOIL5 variable) is employed in the tests below.

4.6.2.a. WEALTH

Alternate Hypothesis I : Relatively poor farm households are tied down to a pattern of subsistence farming, where agricultural productivity levels are fairly consistent vis-à-vis wealthier farm families where income may come from outside employment or from farming itself. Production levels for wealthy rural dwellers may vary considerably, the size of residuals is partially dependent on wealth levels. In the analysis below, the null hypothesis (expressing homoskedasticity in the data set relative to variable in question) is expressed as:

$$H_0: \sigma^2_1 = \sigma^2_2,$$

and the alternate hypothesis (apparent heteroskedasticity) as:

$$H_A: \sigma_1^2 \neq \sigma_2^2.$$

Splitting the data into two wealth level groups (see appendix five for calculation of wealth measurement), the following descriptive statistics provide some insight into the differences in predicted production levels and soil quality.

Table 4.17.a. Wealth Group A (Lower wealth level category)

NAME	N	MEAN	ST. DEV	VARIANCE	MIN	MAX
WEALTH	35	2083.1	933.38	871200	695.00	4010.0
PRODUCT	35	715.70	687.29	472370	1.0072	2150.2
SOIL5	35	267.16	152.70	23319.	82.586	837.41

Table 4.17.b. Wealth Group B (Upper wealth level category)

NAME	N	MEAN	ST. DEV	VARIANCE	MIN	MAX
WEALTH	35	10086.	4444.5	19754000	6295.0	24195.
PRODUCT	35	937.98	917.16	841180	0.71065	2739.2
SOIL5	35	298.14	196.44	38589	96.549	787.16

Agricultural production per hectare for the poorest 35 farmers, on average, is valued at R 715.70 per hectare (approx. \$300 Canadian), compared with R 937.98 for the wealthiest 35 farmers.¹² Soil quality levels (SOIL5) are somewhat lower for the poorest 35 farm families: 267.16 compared to 298.14 for wealthiest 35. Applying a Goldfeldt-Quandt test to assess heteroskedastic tendencies between the upper and lower wealth groups reveals a significant F statistic for the Cobb-Douglas production model employed in section 4.4.2.c.

Table 4.17.c. Goldfeld-Quandt Statistic – Wealth levels

SSE1	SSE2	GQ-STAT	F(critical at $\alpha=0.05$) _{25,35}
56.732	161.06	2.838972	≈ 1.78

In this case, the null hypothesis is rejected in favour of the alternate hypothesis that heteroskedasticity exists relative to the wealth variable.

¹² Looking at the poorest and wealthiest 30 households, respectively, R 667.23 and R 1,131.20 worth of agricultural output per hectare was generated. Productivity levels for the wealthier 30 households was 69.54% greater than the poorest 30.

Correcting for multiplicative heteroskedasticity using the "weight=" in the Shazam program (see appendix three and four) results in the following regression output.

Table 4.17.d. Cobb-Douglas model output (SOIL5): General Statistics

DEPENDENT VARIABLE	MEAN OF DEP. VAR.	R ²	R ² ADJ.	FSTAT (RSS; MEAN)	LEVEL OF SIG. (F _{4,21})	VAR. OF ESTIMATED σ^2
LOG OF PRODUCTIVITY	5.5506	0.3487	0.3162	10.710	0.01	2.5249

Table 4.17.e Cobb-Douglas model output (SOIL5): Coefficient Statistics

VARIABLE	EST. COEFF.	STAND. ERROR	T-RATIO 80 df	P-VALUE	PART. CORR.	STAND. COEFF.	SIG LEVEL
LCAPMO2	0.0185	0.0073	2.536	0.013	0.273	0.2344	0.020
LFERTPR1	0.3540	0.1301	2.721	0.008	0.291	0.2542	0.020
LSLOED2	-0.3282	0.1058	-3.101	0.003	-0.328	-0.3001	0.005
LSOIL5	1.6042	0.3502	4.581	0.000	0.456	0.4416	< 0.001
CONSTANT	-4.2575	1.9580	-2.175	0.033	-0.236	0.0000	0.050

4.6.2.b. EDUCATION

Alternate Hypothesis II : More educated farmers have greater access to off-farm employment opportunities, or conversely, greater capacity to adopt available technologies to increase agricultural productivity. Education – the sum of years of formal education for the primary and secondary household head – may therefore be responsible for heteroskedastic tendencies in the model. The hypothesis that the variance around the mean value of output productivity depends on education reflects the belief that less educated farm households have limited options in production and reduced accessibility to technological advancements. Statistical analysis of farm production according to household educational levels (in years) reveals:

Table 4.18.a. Education Level A (Lower Education Levels)

NAME	N	MEAN	ST. DEV	VARIANCE	MINIMUM	MAXIMUM
HEDUC	35	0.65783	1.0552	1.1134	0.001	3.0000
PRODUCT	35	848.76	828.35	686160	1.0718	2693.1
SOIL5	35	316.23	176.81	31261	96.549	787.16

Table 4.18.b. EDUCATION LEVEL B (Upper Education Levels)

NAME	N	MEAN	ST. DEV	VARIANCE	MINIMUM	MAXIMUM
HEDUC	35	8.4286	2.5928	6.7227	6.0000	15.000
PRODUCT	35	835.18	832.74	693450	0.71065	2739.2
SOIL5	35	245.88	158.43	25102	82.586	727.24

Productivity levels are slightly higher for the 35 households with less formally educated household heads. The less educated group possesses soils that score, on average, 28.61% higher than the latter group using the SOIL5 measurement index. As observed below, in spite of a greater sum of squared error being accorded to more educated households (150.60 versus 105.44 for the less educated), the distinction is not significant at the 5% level. (Irrespective of the proposition outlined above, the larger sum of squared errors [SSE] is placed in the numerator to detect any heteroskedastic influence relative to the variables in question.)

Table 4.18.c. Goldfeld-Quandt Statistic – Educational levels

SSE1	SSE2	GQ-STAT	F(critical at $\alpha=0.05$) _{35,35}
105.44	150.60	1.428287	≈ 1.78

Here, we accept the null hypothesis ($H_0: \sigma_1^2 = \sigma_2^2$) for lack of significance on the GQ statistic.

4.6.2.c. GENDER ANALYSIS

Alternate Hypothesis III: The productivity of farms headed by women will be more variable owing to differential ability to access resources and technical information. The migrant labour phenomenon in Lesotho ensures that a proportionately high number of women are heading household farms. In the sample population, 34.15% of all household farms were headed by women. The possibility of non-identically distributed residuals is considered for two reasons: the resources allocated to female household heads may differ from their male counterparts. Experience or access to male dominated farmer training or institutional support may similarly differ. The impact of any or all these phenomena may result in greater production consistency amongst male farmers. A preliminary statistical analysis of farm production broken into female-versus male-headed farming operations provides the following:

Table 4.19.a. Gender Household Head: Female

NAME	N	MEAN	ST. DEV	VARIANCE	MIN	MAX
GENDER	28	FEMALE				
PRODUCT	28	841.66	1004.6	1009200	0.71065	3790.9
SOIL5	28	296.40	195.36	38164.	82.586	787.16

Table 4.19.b. Gender Household Head: Male

NAME	NUMBER	MEAN	ST. DEV	VARIANCE	MIN	MAX
GENDER	28	MALE				
PRODUCT	28	774.15	729.52	532200	1.6765	2496.5
SOIL5	28	276.37	167.54	28069.	96.549	663.41

According to this analysis, productivity levels for female-headed farms are, on average, 8.72% higher than on male-headed farms. Similarly, soil quality (SOIL5) is also slightly higher on female-headed farms (7.25%). Although the sum of squared errors is slightly higher for female-headed farms, it is not significant at the 5% level:

Table 4.19.c. Goldfeld-Quandt Statistic – Gender Household Head

SSE1	SSE2	GQ-STAT	F(critical at $\alpha=0.05$) _{28,28}
85.203	95.174	1.11703	≈ 1.82

In this case, the null hypothesis that the error terms display homoskedastic tendencies is not rejected.

4.6.2.d. FARM SYSTEMS

Alternate Hypothesis IV: Farmers using a bio-intensive system of farming optimize output levels by building or maintaining soil quality; those that do not are subject to more variable production levels. As previously mentioned, a number of farmers that participated in the survey were involved in a farming system known locally as the Machobane System (for a brief description see appendix six). The Machobane farmers may practise a more monolithic production pattern owing to the prescribed nature of the system. Productivity levels and soil quality statistics for farms practicing this system are contrasted with those practicing more traditional systems of farming:

Table 4.20.a. Non-Machobane Farmers

NAME	N	MEAN	ST. DEV	VARIANCE	MIN	MAX
MACHO	25	no years				
PRODUCT	25	921.74	899.17	808510	0.71065	2543.7
SOIL1	25	28.520	7.4505	55.510	17.000	48.000
SOIL4	25	55.211	30.793	948.22	23.393	141.93
SOIL5	25	280.50	151.33	22901.	96.549	727.24

Table 4.20.b. Machobane Farmers

NAME	N	MEAN	ST. DEV	VARIANCE	MINIMUM	MAXIMUM
MACHO	25	4.7600	7.5348	56.773	1.0000	29.000
PRODUCT	25	1005.5	979.74	959890	1.0072	3790.9
SOIL1	25	34.440	10.583	112.01	18.000	60.000
SOIL4	25	74.421	41.192	1696.8	28.475	160.97
SOIL5	25	316.55	192.56	37080	89.963	837.41

Note: The mean value represents the average number of years the sampled households have been practicing the Machobane system.

Machobane farmers experienced moderately greater productivity levels (9.09% greater) within this restricted sample scenario. For the entire sample, where the mean output level was M848.26 (C\$356.27) per hectare, Machobane farmers had, on average, 17.06% higher output levels. Furthermore, farms which have been employing the system maintain soils that are, on average 5.92 cm deeper, and higher in soil quality measurements SOIL4 and SOIL5 by 34.79% and 12.85%, respectively. While Machobane farmers experience less variable production around the predicted value, it again is not sufficient to establish significance at the 5% level.

Table 4.20.c. Goldfeld-Quandt Statistic – Farming Systems

SSE1	SSE2	GQ-STAT	F(critical at $\alpha=0.05$) _{35,35}
89.408	63.375	1.410782	≈ 1.78

Based on these results, we accept the null hypothesis that $\sigma^2_1 = \sigma^2_2$.

4.6.3. Dummy Variable Analysis

Even though heteroskedasticity may not be significant at the 5 percent level, the possibility remains that different production relationships exist depending on the categorization of the household farm. Households have been divided into groups according to gender and farming system. In order to test for different production relationships between male- and female-headed farms, dummy variables have been applied to model 4.17.d.-e. The production relationship between the two groups is shown to be insignificant with regards to the intercept and slope terms. The same conclusion is reached when a similar inspection is applied to households practicing the Machobane Farm System and those practicing more traditional forms of agricultural

production. In both cases, the maximum level of significance for any coefficient does not exceed the 20% level.

4.7. ALTERNATE MANAGEMENT VARIABLE

While the major focus of this production analysis has been on soil or land quality variables (fertilizer, soil nutrients, and slope), some effort was unsuccessfully expended to establish a significant management variable incorporating education, conservation effort, concern for soil quality, and proportion of wealth invested in farm capital. The effect these management variables have on influencing soil quality are discussed later in this chapter. One consideration that may affect the outcome of such management variables is the timing of data collection. The survey data drew on recorded input and output levels coinciding with the second consecutive year of a debilitating drought. The relative importance of soil quality may increase relative to other factors of production in drought years. There is at least some preliminary suggestion here that maintaining or improving soil quality helps ensure greater output levels, particularly for the case of drought-prone Lesotho.

4.8. MARGINAL PRODUCTIVITY OF SOILS

In chapter three, two equations for determining the marginal physical product were established.¹³ Considering the monetary nature of the dependent variable it is

¹³ Equation 3.24 in chapter three provided a means to calculate the marginal product of a variable in the Cobb-Douglas generalized function which represented the square of the natural log of the original variable. This format could be used to estimate the marginal value of both capital and slope, but not for the soil and fertilizer as they are represented more simply as the log of the true variable value.

appropriate to consider marginal products as additional revenues generated at the margin: marginal revenue product (MRP).

Taking the antilog of the initial equation (see table 4.17.d-e.):

$$(4.1) \quad \ln(\text{productivity}) = \ln(A) + \beta_1 \cdot [\ln(\text{capital})]^2 + \beta_2 \cdot \ln(\text{fertilizer}) + \beta_3 \cdot [\ln(\text{slope})]^2 + \beta_4 \cdot \ln(\text{SOIL5}),$$

yields:

$$(4.2) \quad \text{productivity} = A \cdot e^{[\ln(\text{capital})]^2 \beta_1} \cdot (\text{fertilizer})^{\beta_2} \cdot e^{[\ln(\text{slope})]^2 \beta_3} \cdot (\text{SOIL5})^{\beta_4}$$

Therefore, the marginal value of soil quality (SOIL5) per hectare (MRP) becomes:

$$(4.3) \quad \text{MRP}_4 = \beta_4 \cdot A \cdot e^{[\ln(\text{capital})]^2 \beta_1} \cdot (\text{fertilizer})^{\beta_2} \cdot e^{[\ln(\text{slope})]^2 \beta_3} \cdot (\text{SOIL5})^{\beta_4 - 1}.$$

$$(4.4) \quad \text{MRP}_4 = \partial(\text{productivity}) / \partial(\text{SOIL5}) = \beta_4 \cdot (\text{productivity}) / (\text{SOIL5})$$

Estimating this equation requires input of the mean values of the production variables in the right-hand-side of equation 4.3 above. Their values were as follows:

Table 4.21.a. Mean values of explanatory and dependent variables.

VARIABLE	MEAN (LOG)	MEAN (ANTILOG)
LPRODUCT	5.5506	257.3919
LSOIL5	5.4883	241.8457

Table 4.21.b. Values of coefficients (see tables 4.17.d - e.).

VARIABLE	COEFF.	COEFFICIENT VALUE	STANDARD ERROR	t (0.025) STAT	t (0.05) STAT
LSOIL5	β_4	1.6042	0.3502	1.99	1.65

Applying the above values in equation 4.3 yields:

$$(4.4) \quad \text{MRP}_4 = 1.6042 \cdot (257.3910 / 241.8457)$$

$$= \text{M1.71 per hectare (measured in Maloti currency; equivalent to C\$0.72).}$$

Ninety-five and 90% confidence intervals for equation 4.4 are presented below

Table 4.21.c. Confidence intervals for marginal value of soil quality.

	lower bound	upper bound
90% confidence interval	1.09	2.32
95% confidence interval	0.97	2.45

Multiplying the observed changes in soil quality (SOIL5) by the lower bound value of the 90% or 95% confidence interval provides conservative estimate of the benefits arising from conservation efforts, or the costs attributable to degrading processes.

It was stated earlier in this chapter that the monetary value of changes in soil quality can be assessed by determining the marginal value of soil quality per hectare, its incremental change over time, and the land area in consideration (hectares). The estimated marginal value of soil quality per hectare (SOIL5) can now be multiplied by the number of units of change in the soil index value and multiplied again by the number of hectares under consideration. This calculation yields the estimated economic value attributable to conservation effort, or conversely, the economic cost of degradation.

4.9. SOCIAL, ECONOMIC AND PHYSICAL INFLUENCES ON SOIL QUALITY

This section is devoted to an assessment of the implications of labour availability, conservation effort, socio-political status, farm management variables, and attitudes and concerns to land degradation on the choice soil quality variable, SOIL5. The purpose of this section is to determine initially if soil quality levels can be predicted,

and if so, whether a modelling exercise provides an reasonably accurate means to do so.

4.9.1. CROSS-TABULATIONS

A number of factors could conceivably influence the soil quality of cultivated farmland. Given the cross-sectional data base used for this study, it is difficult to satisfactorily establish the impact any proposed variable has on soil quality because the duration of its influence is not subsumed in the variable itself. Given this limitation, it is necessary to assume that the value accorded to a variable (conservation effort during the year in which the data was collected, for example) is indicative of long run applications. If this assumption is valid, then cross-tabulation analysis should provide a means to establish the significance of potentially influential variables. The nature of the SOIL5 variable – encompassing two soil nutrients, pH levels, and soil depth – should provide a measurement more sensitive to changes in soil management than soil depth alone, which would theoretically require more time to influence (Hausenbuiller, 1978).

4.9.1.a. LABOUR SUPPLY

Hypothesis I: Labour availability influences the ability for a household to employ time intensive conservation measures on family fields (productive labour supply is divided by the number of fields the household possesses). Five different levels of soil quality are listed in ascending order in the leftmost column of the cross-tabulation table below.

The labour variable is also divided into five ascending groups and posted in the first row. Individual boxes in the centre of the chart contain frequency values for the number of times observations were recorded corresponding to the labour category directly above it and the soil quality category to the left. Frequency totals for categories can be observed in the end box of each row and column; the total frequency of observations is contained in the bottom right box. An effort was made to make all the categories of equal size. For some tables where variables are binomial or multinomial in nature, the number of categories for the cross-tabulation table is restricted. Similarly, where the values for certain variables are clumped around certain values, it becomes necessary to tailor the size of the contingency table to address that constraint.

Table 4.22.a. Cross-tabulation table of labour and soil quality variables.

	RLABF1	RLABF2	RLABF3	RLABF4	
SOIL5-1	6	5	7	4	22
SOIL5-2	5	4	7	5	21
SOIL5-3	5	5	2	8	20
SOIL5-4	7	6	4	3	20
	23	20	20	20	83

If a strong relationship between productive labour supply per field and soil quality exists, relatively high frequency values would be expected in the upper left boxes of the table above, suggesting that low levels of labour supply are associated with degraded soils. High values would also be anticipated in the lower right quadrant

suggesting that high labour supply values are associated with high soil quality levels.

A visual inspection suggests that this is not the case.

The table below shows the breakdown of the variables in question, and the mean value and number of observations associated with each category.

Table 4.22.b. Classes of soil quality and labour supply.

CATEGORY	OBS.	MEAN VALUE	CATEGORY	OBS.	MEAN VALUE
SOIL5-1	22	121.5318	RLABF1	23	1.1209
SOIL5-2	21	207.9510	RLABF2	20	1.8728
SOIL5-3	20	285.1831	RLABF3	20	2.8239
SOIL5-4	20	538.4213	RLABF4	20	5.1498

A technical means of determining the existence of a relationship is accomplished by calculating a chi-square statistic for the cross-tabulation table above (see equation 3.2.6). Where the calculated chi-square statistic exceeds the critical value at the 5% level, an association between the variables is assumed to exist; the nature of the association is subsequently assessed where significance exists at the 5% level.

Table 4.22.c. Chi-square statistic on cross-tabulation table.

CALCULATED CHI-SQUARE STATISTIC	CRITICAL CHI-SQUARE STATISTIC
7.271366	16.9190 (0.05 LEVEL)

The relationship between labour supply per field and soil quality is insignificant at the 0.05 level.

4.9.1.b. CONSERVATION EFFORT

Hypothesis II: The total number of hours devoted to conservation work per field¹⁴ influences soil quality levels.

Table 4.23.a. Cross-tabulation table of conservation effort and soil quality variables.

	CLABF1	CLABF2	CLABF3	CLABF4	
SOIL5-1	6	5	7	4	22
SOIL5-2	5	4	7	5	21
SOIL5-3	5	5	2	8	20
SOIL5-4	7	6	4	3	20
	23	20	20	20	83

The following category breakdowns were used to establish the above cross-tabulation table:

Table 4.23.b. Classes of soil quality and conservation effort.

CATEGORY	OBS.	MEAN VALUE	CATEGORY	OBS.	MEAN VALUE
SOIL5-1	21	121.5318	CLABF1	21	1.1209
SOIL5-2	21	207.9510	CLABF2	21	1.8728
SOIL5-3	20	285.1831	CLABF3	20	2.8239
SOIL5-4	20	538.4203	CLABF4	20	5.1498

The calculated chi-square statistic is not significant at the 0.05 level, so hypothesis II is not accepted.

Table 4.23.c. Chi-square statistic on cross-tabulation table.

CALCULATED CHI-SQUARE STATISTIC	CRITICAL CHI-SQUARE STATISTIC
7.2714	16.9190 (0.05 LEVEL)

¹⁴ Conservation labour (CLABF) specifies the number of hours devoted, on average, to conservation effort per field for the crop year in which the output data was collected for. Conservation effort was broken down into several categories and the estimated number of hour expended on each activity was recorded and summed. For more details refer to appendix one.

4.9.1.c. CONSERVATION-SPECIFIC ACTIVITIES: DIGGING OF DIVERSION DITCHES

Hypothesis III: The number of hours spent digging diversion ditches to channel flowing rainwater away from household fields helps maintain relatively higher levels of soil quality.

Table 4.24.a. Cross-tabulation table of diversion digging effort and soil quality variables.

	NO DIVERSION DITCHES	DIVERSION DITCHES DUG	
SOIL5-1	33	22	55
SOIL5-2	22	6	28
	55	28	83

The number of observations and mean values for each category is specified below.

Table 4.24.b. Classes of soil quality and diversion digging effort.

CATEGORY	OBS.	MEAN VALUE	CATEGORY	OBS.	MEAN VALUE
SOIL5-1	55	172.4930	NODIV	55	0.0000
SOIL5-2	28	429.3480	DIVER	28	10.9107

Significance for a relationship between the digging of diversion ditches and soil quality is not established at the 0.05 level.

Table 4.24.c. Chi-square statistic on cross-tabulation table.

CALCULATED CHI-SQUARE STATISTIC	CRITICAL CHI-SQUARE STATISTIC	WITH YATE'S CORRECTION
2.8627	3.8416 (0.05 LEVEL)	2.0922

The hypothesis that a relationship between time expended digging diversion ditches and soil quality exists at the 0.05 level is not accepted.

4.9.1.d. CONSERVATION-SPECIFIC ACTIVITIES: APPLICATION OF KRAAL MANURE TO FIELDS

Hypothesis IV: The time allocated each year to the application of kraal manure to fields (MAN#) is positively related to the recorded soil quality level.

Table 4.25.a. Cross-tabulation table of manure application (hours) and soil quality variables.

	LOW MANURE INPUT (MAN1)	HIGH MANURE INPUT (MAN2)	
SOIL5-1	13	23	36
SOIL5-2	23	23	46
	36	46	82

The frequency of observations and mean values for each category are present below.

Table 4.25.b. Classes of soil quality and manure application (hours).

CATEGORY	OBS.	MEAN VALUE	CATEGORY	OBS.	MEAN VALUE
SOIL5-1	36	151.9761	MAN1	36	1.2361
SOIL5-2	46	389.5667	MAN2	46	15.6739

Table 4.25.c. Chi-square statistic on cross-tabulation table.

CALCULATED CHI-SQUARE STATISTIC	CRITICAL CHI-SQUARE STATISTIC	WITH YATE'S CORRECTION
1.5818	3.8416 (0.05 LEVEL)	1.0681

The hypothesis that hours spent applying kraal manure to fields and soil quality are positively related is rejected at the 0.05 level.

4.9.1.e. FAMILY RELATIONSHIP WITH LOCAL CHIEF

Hypothesis V: A family's relationship with the local chief (land-giving authority) is positively related to the quality of farmland (soil quality) that is allocated to it.

Households are defined as having: (1) no political connections, or (2) maintaining a

current or descendant family member who is/was one of the chiefs advisors (headmen).

A cross-tabulation table and category breakdown chart follow:

Table 4.26.a. Cross-tabulation table of household political status and soil quality variables.

	No Political Affiliation	Political Affiliation	
SOIL5-1	47	16	63
SOIL5-2	16	3	19
	63	19	82

Table 4.26.b. Classes of soil quality and household political status.

CATEGORY	OBS.	MEAN VALUE	CATEGORY	OBS.	MEAN VALUE
SOIL5-1	63	205.6473	No Polit. Tie	63	0
SOIL5-2	19	549.2329	Polit. Tie	19	1

The chi-square value recorded below suggests that there is no significant relationship between soil quality and the socio-political standing of households in the region of Lesotho where data collection for this study took place (see methodology in chapter one). The hypothesis that a positive relationship between the two variables exists is not accepted at the 0.05 level of significance.

Table 4.26.c. Chi-square statistic on cross-tabulation table.

CALCULATED CHI-SQUARE STATISTIC	CRITICAL CHI-SQUARE STATISTIC	WITH YATE'S CORRECTION
0.7568	3.8416 (0.05 LEVEL)	0.3134

4.9.1.f. FARMING SYSTEMS

Hypothesis VI: Farmers using the Machobane farming system, summarized in appendix six, experience relatively rapid increases in soil quality (note: many farmers

have been using the system for only one year). Cross-tabulations and statistics describing the category breakdowns are provided below.

Table 4.27.a. Cross-tabulation table of farming systems (Machobane vs. more traditional systems) and soil quality variables.

	Traditional farming	Machobane system	
SOIL5-1	30	17	47
SOIL5-2	17	18	35
	47	35	82

Table 4.27.b. Classes of soil quality and farming systems.

CATEGORY	OBS.	MEAN VALUE	CATEGORY	OBS.	MEAN VALUE
SOIL5-1	47	174.4996	Traditional	47	0
SOIL5-2	35	433.9921	Machobane	35	1

Table 4.27.c. Chi-square statistic on cross-tabulation table.

CALCULATED CHI-SQUARE STATISTIC	CRITICAL CHI-SQUARE STATISTIC	WITH YATE'S CORRECTION
1.9091	3.8416 (0.05 LEVEL)	1.34

The linkage between the farming systems and soil quality is not significant at the 0.05 level; the original hypothesis is not accepted.

4.9.1.g. CONCERN FOR DEGRADATION

Hypothesis VII: Farmers who express a concern for the farmland degradation as a constraint to agricultural production make successful efforts to improve soil quality. Figure 4.1 displayed the relative ranking of 12 constraints to agricultural production as perceived by farmers. One of the constraints, erosion or land degradation, therefore was ranked from one to twelve among the other constraints. Those that ranked

erosion as 12, perceive degradation to be the least constraining item from the list. For this reason, the mean values for the erosion variable are listed in descending order in tables 4.28.a and 4.28.b. below.

Table 4.28.a. Cross-tabulation table of concern for land degradation and soil quality variables.

	erosion1	erosion2	erosion3	
SOIL5-1	14	11	5	30
SOIL5-2	7	12	6	25
SOIL5-3	11	9	8	28
	32	32	19	83

Table 4.28.b. Classes of soil quality and concern for land degradation.

CATEGORY	OBS.	MEAN VALUE	CATEGORY	OBS.	MEAN VALUE
SOIL5-1	30	134.9866	erosion1	32	4.5
SOIL5-2	25	247.4380	erosion2	32	8.6296
SOIL5-3	28	478.9169	erosion3	19	11.0741

The relationship between the concern for land degradation (as specified) and soil quality is not significant at the 0.05 level.

Table 4.28.c. Chi-square statistic on cross-tabulation table.

CALCULATED CHI-SQUARE STATISTIC	CRITICAL CHI-SQUARE STATISTIC
3.0589	9.4877 (0.05 LEVEL)

4.9.2. Socio-economic influences on land degradation: concluding remarks

Of the seven hypothesized influences on soil quality none are significant at the 0.05 or 0.10 level. Three factors that may contribute to this result were previously mentioned: data collection errors, inaccurate variable specification, and the inappropriateness of

applying a cross-sectional data base to assess dynamic relationships. Nonetheless, the results suggest that some of the explanations offered by authors such as Blaikie, (1988) and Stocking (1988) regarding socio-economic influences on land degradation in the developing world mentioned earlier, may not be valid in Lesotho. The validity of such explanations can be addressed through empirical analysis which is currently lacking. If the specification and magnitude of factors influencing degradation are well understood, then project activities or public policies aimed at maintaining or improving soil quality can be more effectively formulated.

CHAPTER FIVE

CONCLUSION

5.1. THESIS REVIEW

This chapter concludes the thesis by summarizing the chapters on physical and economic aspects of soil quality and land conservation, production economics, and the empirical study undertaken in Lesotho, Africa and bringing them into a more unified perspective.

The introductory chapter suggested that the purpose of the thesis was to establish a model of agricultural production for the lowlands of Lesotho so that a regional marginal value of soil could be determined. Determining the marginal value of soil quality was seen as a necessary precursor to establishing the value of conservation-oriented efforts with reasonable accuracy. It would also establish a means of assessing the impact declining soil quality has on reduced agricultural output over time. A second objective was to determine the nature and dynamics of socio-economic factors that were hypothesized to influence soil quality levels. To properly address these issues, two chapters devoted to examining relevant issues in soil science, land conservation, and production economics were provided before applying econometric analysis to the stated objectives.

In chapter two, an economic perspective of soil quality was introduced by the notion that as farmers allocate land to the use where the most profitable return is

secured: either cropland, pasture, or wasteland. While an inventory perspective on land usage alludes to soil quality indirectly, land use was viewed as being a function of several exogenous parameters that discount the effectiveness of such a soil quality barometer.

The severity of the land degradation problem in Lesotho was also discussed in the second chapter. Sixty years ago the colonial government, of what was then called Basutoland, stated that soil erosion was perhaps the most serious obstacle to socio-economic growth. In spite of the priority that land conservation activities have received since 1935, the problem continues to worsen. Principal components and interrelationships of factors that are seen to influence cropland degradation were outlined in figure 2.1. It was latter suggested that farmers may not see the problem of crop failure as being associated with soil erosion (in contrast to the views of "experts"), but rather with weak soils among other forces of nature. The focus of the paper then turned to address soil quality as an essential element of agricultural production.

The approach the thesis takes in gauging soil quality as a function of agricultural production was presented in chapter two; the need for an acceptable soil quality index was then highlighted. A discussion of existing indices prefaced a section describing numerous qualitative attributes of soil that may be used to generate a composite soil quality variable for applied research purposes.

Chapter three discussed the nature of economic production functions in graphical and functional forms. Concepts such as average, marginal, and total physical

product were discussed along with factor elasticity, marginal rate of technical substitution and elasticity of substitution. The latter two points were not pursued in the subsequent analysis because of the difficulty posed in estimating their values and the nature of the explanatory variables (soil quality is not substitutable with fertilizer in the long run; field slope can not be traded off with other variables, etc.) .

Four production functions – linear, quadratic, Cobb-Douglas, and translog – were presented as models that could be estimated through econometric analysis. Problems that may arise due to multicollinearity and heteroskedasticity , two problems associated with cross-sectional data and production functions such as the Cobb-Douglas and translog, were then discussed along with some remedial measures to mitigate their influences. Chapter three concluded with some remarks about previous efforts to estimate production models in developing countries.

Chapter four discussed the nature of the production functions to be estimated given various constraints involved in data collection. Explanatory production variables applied in the subsequent analysis included labour supply, capital stock, fertilizer, slope and soil quality. A theoretical and statistical assessment of each of these variables was then provided. It was determined that the labour supply variable was not suitably correlated with output productivity to be included in a modelling exercise.

Using the OLS method of estimation, the Cobb-Douglas function appeared to be the most appropriate model given the data set collected by the author and three survey assistants. From a total of six soil quality variables, one was determined to be

the most highly correlated with the productive capacity of cultivated land. This soil quality variable (SOIL5) is a composite variable represented as follows:

$$(5.1) \quad \text{SOIL5} = \text{DEPTH} \cdot (\text{PHOSPHORUS} + \text{POTASSIUM LEVELS}) \cdot \text{PH LEVEL}.$$

In the Cobb-Douglas model in which it was applied, multiplicative heteroskedasticity associated with wealth levels was apparent. The problem was partially remedied by dividing the explanatory variables and residual in the model by the square root of the wealth level (see appendix five) associated with each observation. This was facilitated by applying a weight factor to the model which was estimated using the Shazam Econometrics Computer Program (ed. 7.0; White, 1993). The R^2 value was viewed as being reasonably high given that no controls were applied in the data collection process coupled with the cross-sectional nature of the data. The marginal value of SOIL5 at the mean was then determined to be M1.71 (C\$0.72).

The latter section of chapter four dealt with the influence socio-economic variables have on soil quality (again, SOIL5 was applied). A number of variables were included in the analysis: labour supply, conservation labour application (total, diversion digging, and manure application specified in hours), socio-political status, farming system application, and attitudes and concerns towards land degradation. The conclusion was that no connection between soil quality and these variables can be established at the 5% level of significance. Possible explanations allude to the need for time series data or better variable specification.

5.2. PRACTICAL IMPLICATIONS

As demonstrated in the empirical section of this thesis, soil quality is a crucial element of agricultural production. Maintaining or improving soil quality is an important first step towards ensuring and sustaining food production for rural households. Projects which advocate agricultural systems such as the Machobane System appear to assist farmers to generate higher output and soil quality levels. Although the average level of output and soil quality for the Machobane farmers is above average, the relationship between the two is, however, not significant. Applying a time series data base to this problem, it could be discerned whether farmers adopting the system already had superior soil quality and agricultural output, or that the improvement is attributable to the farming system.

Scoring for the SOIL5 variable for the Machobane and the more traditional farming systems was 316.55 and 280.50 respectively. This differential value in SOIL5 would lie between M34.97 and M88.32 (C\$14.69 and C\$37.09) as predicted multiplying the upper and lower bound values for the marginal value of SOIL5 (95% confidence interval) by the differential. The actual difference in output between the two groups as presented in table 4.20.a. and 4.20.b. was M83.76.

Conservation-oriented projects could gain insight into their effectiveness by tracking soil quality attributes over time. Including physical attributes such as bulk density and infiltration rates, coupled with yearly soil sampling may help enhance the significance of the soil quality variable and the explanatory power of the model it appears in. Participating farmers could be included in the process, with their soils

subject to annual scoring and economic evaluation. Project-led research performed successfully over a number of years could work to provide a revised regional modelling framework and help to estimate the benefits accruing to farmers as a result of the project's conservation effort.

Conservation-oriented projects are often mandated to perform work which maintains or improves soil quality within a project area or among fields cultivated by household participants. As such, it may be misleading if evaluation teams estimate the value of enhanced production alone as the benefit attributed to the project. The value of enhanced production may arise due to changes in farm management procedures and applications that have negligible or minor impacts on soil quality. An evaluation procedure which measures changes in appropriately defined soil quality levels is a valid means of addressing benefits in line with the mandate of conservation projects.

In closing, this paper has presented a viable means for estimating a marginal economic value of soil quality. Future research in this area would undoubtedly gain where a time series data base of reasonable quality is applied. Future research into the socio-economic and political influences on land degradation, possibly along the lines of the analysis presented in the latter section of chapter four, could also yield valuable information. Conservation programs could be improved when a better understanding of the relationships between soil quality and socio-economic and political variables is established. That all the hypothesized variables were insignificant at the 0.05 level (even at the 0.10 level; see pages 80 through 90), in spite of the cross-sectional data

base employed, provides a rationale for challenging contemporary thought on the subject. Further empirical analysis could work to support or refute similar hypotheses.

APPENDIX ONE

III. FIELD CROPS: SEED INPUT (KG) AND TYPE (LAST YEAR) ⇨

[illegible]

IV. LAST YEAR'S OUTPUT (FAMILY ENTITLEMENTS)⇒

[illegible]**V. OUTPUT MARKETED (FAMILY ENTITLEMENTS; kg OR MALOTI)**[illegible]

VI. OUTPUT FROM BEST YEAR (19) OUTPUT MARKETED (19)

F I E L D	M A I Z E	S O R G H	W H E A T	P O T A T O	P E A S E	B E A N S	P U M P
1.							
2.							
3.							
4.							
5.							
6.							
TOT. AL							

F I E L D	M A I Z E	S O R G H	W H E A T	P O T A T O	P E A S E	B E A N S	P U M P
1.							
2.							
3.							
4.							
5.							
6.							
TOT. AL							

VII. GARDENS

P L O T	O W N E R	I R R I G	F E R T	M A N U R	P E S T	G R O W	U N I T	M A R K	G R O W	U N I T	M A R K

VIII. FRUIT TREES AND MPT's FROM LAST YEAR'S HARVEST (fruit marketed in 10 or 25 buckets; mark buk10 or buk25)

	peach	apple	apricot		willow	poplar	pine
existing trees (approx. total)							
marketed							
position							
propagate							
purpose							

LEGEND
Propagate: yes(1) no(0)
Purpose:
1. firewood 2. construction
3. fodder 4. soil mainten.
5. windbreak 6. food value
7. other (specify)
Position:
1. field 2. grazeland
3. garden 4. donga
5. around home

IX. HOUSEHOLD POSSESSIONS

Items	#	Item/s	#	Items	#	Items	#	Items	#
field		sledge		oxen		rondavels		cupboard	
planter		tractor		dairy cow		storerooms		latrine	
plough		hoe		other cattle		kraals		sofas	
harrow		sheep		chickens		garden plots		bakkie/car	
cultivator		goats		flats		fruit trees		wheelbarrow	
cart		horses		flats = iron-roofed houses add add * where free access or Maloti		fence		non-farm tools	
yoke		donkeys				radio		television	

X. AWARENESS, RESPONSE AND EXISTENCE OF CONSERVATION MEASURES:

	resp	exist	hrs. per year		resp	exist	hrs. per year
tree plant				donga struct.			
dams				grass planting			
diversions				manure			

responses: 0=no opinion; 1=good
 2=suggestion
 exist: 0=never exist
 1=poorly maintained
 2=maintained
 3=built & maintained
 year=years present

XI. If respondent would like to do more conservation work, rank constraints or circle: NO
(skip next box)

lack labour		lack money for inputs		unpleasant work			
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XII. Reasons for not considering undertaking more or any conservation work

not worth labour or money input		unpleasant work					
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XIII. Perception of risk: uncertainty in farming:

Elements of insecurity	Rank	Seed allocation (40 seeds)
Seed availability		
Poor germination		
Land security		
Pests		
Drought		
Fertiliser availability		
Theft		
Insufficient Labour		
Erosion		
Lack of draught power		
Lack of farm implements		
Hail		

XIV. Allocation of agricultural funds

hired labour (crops) M _____
 livestock expenses (vet, herding, etc.) M _____
 fertilizer M _____
PRODUCTION EXPENSES
 field M _____
 implements & hire M _____
 fruit trees or MPT M _____
 tractor M _____
 garden (all) M _____
 other M _____
TOTAL EXPENSE: M _____

APPENDIX TWO

SURVEY GUIDE

PREAMBLE

This guide was originally written to provide survey assistants some guidance to the questions presented on the survey questionnaire in appendix one. A few minor editorial changes have been made to make it reasonably accessible to the general reader. (Some editorial changes to the original survey were also necessary in order to comply with standard text margin specifications.)

INTRODUCTION

The purpose of this questionnaire is to analyze farming systems of Lesotho and determine the magnitude of key variables in the production process. A focus on attitudes and perceptions of the problem of land degradation is provided along with the awareness of remedial conservation practices and the actual physical response of the household. The inputs that go into the production process (and their characteristics) are responsible for seasonal output, but the treatment of the land has implications on medium to long term production levels.

As previously stated, this thesis work is leading towards providing "a means to assess the value of soil quality at the margin and assess the implications of various socio-economic influences on land degradation." It is targetted to provide a framework for analyzing the strengths and possible weaknesses of conservation-based agricultural (CBA) systems in Lesotho based on their ability to physically, chemically, and biologically transform soils to allow for enhanced production.

Your participation on the team aimed at establishing a data base to address the issues stated above is greatly appreciated. The quality of your work will be reflected in the quality of data that is to be produced and the degree to which it can lead to possible insights into land degradation and agricultural production in Lesotho.

Below is a background reference to the questions on the survey questionnaire, which you can consult in my absence. If you do not recall some of the questioning formats, please direct your questions to me, or leave the question to last and consult with me before going on to the next survey. I greatly appreciate your hard work !

PAGE ONE OF SURVEY

I. HOUSEHOLD

"Relation" refers to the relationship between the family and the village chief. Mark "2" where the family currently has a member who is an advisor (or headman) to the chief; a "1" signifies that the household previously (within 10 years) had a member who acted as an advisor; and, "0" to signify that no such relationship existed. Referring to the other questions down the left-hand margin, there are two possible "household heads" in the first question. Two are provided in case the first head is working off-farm so a second (typically a woman) takes over the responsibility of managing the farm. For "education," simply specify the number of years that the the first and second household head have attended school. For "head experience" and "2nd head experience," you should specify how long the respective head has been farming their own land (usually since they were married).

"Status" should not provide any problems (see legend below). "Wks/yr" specifies the typical number of months that the household head is off the farm (over the past two to three years). Work type: refer to legend below and mark "f" for full-time and "p" for part-time work.

The "Return (for W, S, B)" is aimed at determining for which period off-farm workers return to the farm for agricultural activities (see legend below). For the box "bring inc." you should try to determine how much income the worker brings back to the home. Respondents may be reluctant to answer this question and should be told that it is optional (pushing them may create suspicions on the part of the interviewee that will negatively affect the remainder of the survey). It may be better to leave this question to last (this will be discussed after we do a few interviews together). If the question is left unanswered, we will have to determine external income brought home by analyzing the job position of workers (to estimate the wages or salary) and the amount of time spent on-farm (to estimate how much may remain with the household). Completing the top section, "Ag Exp" refers to agricultural exposure, or the number of times that the farmer has (a) been visited by an extension agent, and (b) the number of farmers' training courses they have participated in.

II. FIELDS

II. A. This question will require considerable study before you undertake the first survey.

The words written across the top of the page have the following meanings:

field - simply write down "1" for the first field, "2" for the second, and so on.

own - here you should specify the type of ownership involved for the field in question: o (own); si (share-in); so (share-out); hi (hire-in); ho (hire-out); l (lend); b (borrow).

posit.- relates to (3) flat, (2) slight incline, and (1) moderate to steep incline

years - specify the number of years that the farmer has been working the land (normally since marriage where land is owned) including the number of years that a sharecropping arrangement has been in effect (where the land is not owned by the household)

confid. - is the owner confident (mark "c") or unconfident (mark "u") of being able to continue farming the field in question year after year

maize seed - where respondent doesn't know the acre amount, ask them how much maize seed would normally be planted on the area in order to assess the size. Maize seed can be measured as kg, p = package (10kg), t = tin (normally 20 kg, but ensure this is correct, otherwise estimate kg.

acres - specify Sesotho acres (mark with [s]), English acres (mark with [e]) if respondent knows amount

worth - for this question, the respondent should be asked the following question: "Given the manner in which you plowed, planted, weeded, and harvested this field last year, what is the minimum number of bags (70 kg) of output you feel is necessary to justify the time, effort and money that you invested in the field."

- change -** have you seen a change in the fertility of the field in question over the past years (?): (1) not change, (2) slight change, and (3) significant change
- fert -** the farmer should specify the perceived fertility level of the field where: 1= low fertility, 2 = moderate fertility, and 3= good to excellent fertility
- lehlaba (sandy), letsopa (clayey), selokoe (loamy) -** farmer should specify which characterizes the field in question (mark ☐)
- fertil. -** specify amounts of fertilizer used on field in bags (b), kg (k), or maloti (M)
- manure-** amount of manure (estimated) applied to field: use (k) for kiribae (wheelbarrow); sc for small scotch cart; bc for large scotch cart
- pestic. -** specify amounts of pesticides used on field in bottles (t) or bags (b)
- herbic. -** specify herbicide application in same manner as pesticides
- plow -** farmer plowed with own oxen (write "1") or other's oxen (2) or own tractor (3) or other tractor (4). Also include whether farmer plowed on time (t) or late (a)
- concern -** the farmer is not concerned about the degradation on the land (0), slightly concerned (1), or very concerned (2)
- improve -** does farmer see no need to improve the field(0) through conservation practices such as manure application, tree planting, diversion digging, etc, or, is there a need to improve the land (1)
- problems -** specify main two problems encountered on field: 1 = seed not available, 2 = fertilizer not available, 3 = poor germination, 4 = insecurity of ownership, 5 = pests, 6 = drought, 7 = theft or trespassing, 8 = insufficient

labour, 9 = hail, 10 = lack of draught power, 11 = land degradation or erosion, 12 = lack of implements

machoba- the number of year the household has been practising the Machobane Farm system should be specified for the respective field

III. FIELD CROPS: SEED INPUT (KG) AND TYPE (LAST YEAR) ⇒

Specify the amount in kg or weight category previously discussed (see notes). For seed type, specify as "h" (hybrid) or "s" (sesiu or saved seed). If any inconsistencies exist, refer to the following or ask for assistance.

- Specify the amount of seed that was planted where p = packages, k = kg, t = tins (20 kg) and the amount that was harvested where b = bags (70 kg), k = kg, t = tins (20 kg), and s = scotch carts.

IV. LAST YEAR'S OUTPUT (FAMILY ENTITLEMENTS)⇒

Family entitlements refer to the amount the family took in for themselves from the field in question. It is necessary to calculate the weight of output for later analysis, so be sure that whatever measurements you use can be later converted into kilograms.

V. OUTPUT MARKETED (FAMILY ENTITLEMENTS; kg OR MALOTI)

For output marketed, provide the weight of output and the price if possible.

VI. OUTPUT FROM BEST YEAR (19__) OUTPUT MARKETED (19__)

This section is provided so that where major discrepancies occur, the productive capacity of a fields' soil can be estimated.

VII. GARDENS

VIII. FRUIT TREES AND MPT's FROM LAST YEAR'S HARVEST (fruit marketed in 10 or 25 buckets; mark buk10 or buk25)

Both of the above categories were not applied in the empirical section of the thesis so they are not presented here.

IX. HOUSEHOLD POSSESSIONS

All that is required in this section is to note the number of listed items the household possesses. A calculation of household wealth and farm capital will be derived from this so please use caution not to confuse items with one another.

X. AWARENESS, RESPONSE AND EXISTENCE OF CONSERVATION MEASURES:

The first question in this section (resp) has been deleted. "Exist" refers to whether the activity or structure (e.g. contour bund) exists on the farm. The second column requires a number value for the estimated hours devoted to an activity per year (if possible, estimate by breaking down the activity into sub-tasks and sum hours). Where an activity requires only one-time efforts such as dam construction, put an "X" through the "year" column. Otherwise try to get respondent to estimate the number of years that activity has been undertaken.

XI. If respondent would like to do more conservation work, rank constraints or circle: NO
(skip next box)

XII. Reasons for not considering undertaking more or any conservation work

For above two questions, simply rank the appropriate responses in appropriate order; add other titles as required.

XIII. Perception of risk: uncertainty in farming:

This question requires that each element of insecurity in farming (constraint to production) is ranked from one to twelve (one is the biggest constraint, twelve is the least significant).

IV. A: This section is relatively self-explanatory (see sheet provided to assist you with undertaking this question with the respondent). In the first section, respondents should rank the priorities of different budget allocation categories (see notes for category composition). For the next box, you will provide the respondent 40 seeds. The placement of seeds coincides with the degree they desire to eradicate the element of insecurity: eight seeds allocated to one box "buys" complete protection, one seed provides only limited protection. We will have a chance to go through this together so that a unified approach is provided by all surveyors. Lastly, cumulative willingness to pay (WTP) refers to the respondents WTP for the insurance coverage as laid out by the seed allocation.

XIV. Allocation of agricultural funds

Survey respondents are requested to estimate the expense they incurred over the previous year (so that expenses are corresponding to the output recorded earlier). Most responses should fit into one of the categories presented, however, if it is necessary to add another category, do so in the box required.

APPENDIX THREE

```

                                file 4 c:\metrics\datatwo.txt
read (4) int int1 fields vill rlab plab flab clab wealth cap capmox capmech &
      ph om p k cropin fprod sloedit anal depth gender macho heduc &
      manure man2 tcon mngt1 fert1 fert /skiplines=1
genr metre1=anal*.8361
genr hectare=metre1/10000
genr lmetre1=log(metre1)
genr lmetre2=lmetre1**2
genr product=fprod/hectare
genr lproduct=log(product+1)
?stat lproduct/mean=lpr1
genr lprod1=lproduct/lpr1
genr lrlab=log(rlab)
genr lplab=log(plab)
genr lflab=log(flab)
genr rflab=rlab/fields
genr pplab=plab/fields
genr fflab=flab/fields
genr lrflab=log(rflab)
genr lpflab=log(pflab)
genr lfflab=log(fflab)
genr lcap=log(cap)
genr lcap2=log(cap)
genr wealth2=wealth**2
genr lwealth=log(wealth)
genr capmo2=capmox**2
genr capme2=capmech**2
genr lcapmo=log(capmox)
genr lcapme=log(capmech)
genr lcapmo2=lcapmo**2
?stat lcapmo2/mean=lca2
genr lcap21=lcapmo2/lca2
genr lcapme2=lcapme**2
genr fertpr1=(fert+1)/hectare
genr fertpr2=fertpr1**2
genr lfertpr1=log(fertpr1)
genr lfertpr2=lfertpr1**2
?stat lfertpr1/mean=lf1
genr lfert1=lfertpr1/lf1
?stat lfertpr2/mean=lf2
genr lfert2=lfertpr2/lf2
genr sloed2=sloedit**2
genr lsloed=log(sloedit)
genr lsloed2=lsloed**2
?stat lsloed2/mean=ls12

```

```

genr lslo21=lsloed2/ls12
genr soil1=depth
?stat om/mean=om1
genr om21=om/om1
?stat p/mean=p1
genr p21=p/p1
?stat k /mean=k1
genr k21=k/k1
genr soil2=om21+p21+k21
genr soil3=depth*(om21+p21+k21)
genr soil4=depth*(p21+k21)
genr soil42=soil4**2
genr soil5=depth*ph*(p21+k21)
genr soil52=soil5**2
genr soil6=depth*ph*(om21+p21+k21)
genr lsoil1=log(soil1)
genr lsoil2=log(soil2)
genr lsoil3=log(soil3)
genr lsoil4=log(soil4)
genr lsoil42=lsoil4**2
genr lsoil5=log(soil5)
genr lsoil52=lsoil5**2
genr lsoil6=log(soil6)
?stat lsoil5/mean=lso5
genr lsoil51=lsoil5/lso5
genr cs=capmox*sloedit
genr cf=capmox*fertpr1
genr c5=capmox*soil5
genr sf=sloedit*fertpr1
genr s5=sloedit*soil5
genr f5=fertpr1*soil5
genr lcf=lcapmo*lfertpr1
genr lcs=lcapmo*lsloed
genr lc5=lcapmo*lsoil5
genr lfs=lfertpr1*lsloed
genr lf5=lfertpr1*lsoil5
genr ls5=lsloed*lsoil5
stat product rlab plab flab rflab pflab fflab/pcor
stat lproduct lrlab lplab lflab lrflab lpflab lfflab/pcor
stat product fertpr1 fertpr2/pcor
stat lproduct lfertpr1 lfertpr2/pcor
stat product capmech capme2 capmox capmo2/pcor
stat lproduct lcapme lcapme2 lcapmo lcapmo2/pcor
stat product sloedit sloed2/pcor
stat lproduct lsloed lsloed2/pcor

```

```

stat product soil1 soil2 soil3 soil4 soil5 soil6 /pcor
stat lproduct lsoil1 lsoil2 lsoil3 lsoil4 lsoil5 lsoil6 /pcor
ols product capmox sloedit fertpr1 soil1
ols product capmox sloedit fertpr1 soil4
ols product capmox sloedit fertpr1 soil5
ols product capmox capmo2 sloedit sloed2 fertpr1 fertpr2 soil5 soil52 cs cf c5 sf s5 f5
ols lproduct lcapmo2 lfertpr1 lsloed2 lsoil1
ols lproduct lcapmo2 lfertpr1 lsloed2 lsoil4
ols lproduct lcapmo2 lfertpr1 lsloed2 lsoil5
ols lproduct lcapmo lcapmo2 lsloed lsloed2 lsoil5 lsoil52 lfertpr1 lfertpr2 lcs lc5 lcf ls5 lfs
lfs
stat lfertpr1 lcapmo2 lsloed2 lsoil1 lsoil4 lsoil5/pcor
stat fertpr1 capmox wealth sloedit/pcor
stat fertpr1 p k om ph/pcor
?ols lsoil4 lfertpr1
test lfertpr1
?ols lsoil4 lfertpr2
test lfertpr2
?ols lsoil4 lsloed2
test lsloed2
?ols lsoil5 lfertpr1
test lfertpr1
?ols lsoil5 lfertpr2
test lfertpr2
?ols lsoil5 lsloed2
test lsloed2
?ols lfertpr1 lcapmo2 lsloed2
test
test lcapmo2=0
test lsloed2=0
end
?ols lsoil5 lfertpr1 lcapmo2 lsloed2
test
test lfertpr1=0
test lcapmo2=0
test lsloed2=0
end
?ols lsoil4 lfertpr1 lcapmo2 lsloed2
test
test lfertpr1=0
test lcapmo2=0
test lsloed2=0
end
stat lcapmo2 lsloed2 lfertpr1 lsoil1 lsoil4 lsoil5/pcor
sort gender product lproduct lcapmo2 lfertpr1 lsloed2 lsoil5 soil5

```

```

smpl 1 28
stat gender product soil5
?ols lproduct lcapmo2 lfertpr1 lsloed2 lsoil5
gen1 sse1=$sse
smpl 58 85
stat gender product soil5
?ols lproduct lcapmo2 lfertpr1 lsloed2 lsoil5
gen1 sse2=$sse
gen1 GQgender=sse2/sse1
print GQgender
smpl 1 85
sort int wealth product lproduct lcapmo2 lfertpr1 lsloed2 lsoil5 soil5
sort wealth product lproduct lcapmo2 lfertpr1 lsloed2 lsoil5 soil5
smpl 1 35
stat wealth product soil5
?ols lproduct lcapmo2 lfertpr1 lsloed2 lsoil5
gen1 sse1=$sse
smpl 51 85
stat wealth product soil5
?ols lproduct lcapmo2 lfertpr1 lsloed2 lsoil5
gen1 sse2=$sse
gen1 GQwealth=sse2/sse1
print GQwealth
smpl 1 85
genr wgt=1/wealth
ols lproduct lcapmo2 lfertpr1 lsloed2 lsoil1/ weight=wgt anova
ols lproduct lcapmo2 lfertpr1 lsloed2 lsoil4/ weight=wgt anova
ols lproduct lcapmo2 lfertpr1 lsloed2 lsoil5/weight=wgt anova
test
test lsloed2=0
test lcapmo2=0
test lfertpr1=0
test lsoil5=0
end
test lsloed2
test lcapmo2
test lfertpr1
test lsoil5
ols lproduct lcapmo2 lfertpr1 lsloed2 lsoil5/weight=wgt anova
confid lcapmo2 lfertpr1 lsloed2 lsoil5
gen1 L1=log(2899)**2
gen1 L2=log(8.3)**2
gen1 MPP0=1.6042*exp(-4.2575)*exp(0.018467*L1)*(148.5**0.35400)*exp(-
0.32824*L2)*(284**(1.6042-1))

```

```

gen1 MPP1=0.9108*exp(-8.13434)*exp(0.00405*L1)*(148.5**0.09638)*exp(-
0.53780*L2)*(284**(0.91080-1))
gen1 MPP2=2.29800*exp(-0.38066)*exp(0.03288*L1)*(148.5**0.61160)*exp(-
0.11870*L2)*(284**(2.29800-1))
gen1 MPP3=1.0240*exp(-7.50386)*exp(0.006395*L1)*(148.5**0.13830)*exp(-
0.50370*L2)*(284**(1.02400-1))
gen1 MPP4=2.1850*exp(-1.01114)*exp(0.03054*L1)*(148.5**0.56970)*exp(-
0.15280*L2)*(284**(2.18500-1))
**estimated MPP of soil quality (SOIL5) per hectare
print MPP0
**lower bounds at 95% confidence interval
print MPP1
**upper bounds at 95% confidence interval
print MPP2
**lower bounds at 90% confidence interval
print MPP3
**upper bounds at 90% confidence interval
print MPP4
smpl 1 85
sort int heduc product lproduct lcapmo2 lfertpr1 lsloed2 lsoil5 soil5
sort heduc product lproduct lcapmo2 lfertpr1 lsloed2 lsoil5 soil5
smpl 1 35
stat heduc product soil5
?ols lproduct lcapmo2 lfertpr1 lsloed2 lsoil5
gen1 sse1=$sse
smpl 51 85
stat heduc product soil5
?ols lproduct lcapmo2 lfertpr1 lsloed2 lsoil5
gen1 sse2=$sse
gen1 GQheduc=sse2/sse1
print GQheduc
smpl 1 85
sort int macho product lproduct lcapmo2 lfertpr1 lsloed2 lsoil5 soil1 soil4 soil5
sort macho product lproduct lcapmo2 lfertpr1 lsloed2 lsoil5 soil1 soil4 soil5
smpl 1 25
stat macho product soil1 soil4 soil5
?ols lproduct lcapmo2 lfertpr1 lsloed2 lsoil5/weight=wgt
gen1 sse1=$sse
smpl 61 85
stat macho product soil1 soil4 soil5
?ols lproduct lcapmo2 lfertpr1 lsloed2 lsoil5/weight=wgt
gen1 sse2=$sse
gen1 GQmacho=sse1/sse2
print GQmacho
smpl 1 85

```



```
stat product capmox fertpr1 sloedit soil5
stat lproduct lcapmo lfertpr1 lsloed lsoil5
stat lproduct lcapmo2 lfertpr1 lsloed2 lsoil5
genr lcapmo2=log(capmo2)
genr lsloed2=log(sloed2)
ols lproduct lcapmo2 lfertpr1 lsloed2 lsoil5/weight=wgt
stop
```

□

APPENDIX FOUR

```

UNIT 6 IS NOW ASSIGNED TO: c:\metrics\maxout1.out
|_file 5 c:\metrics\maxim3b.sha
UNIT 5 IS NOW ASSIGNED TO: c:\metrics\maxim3b.sha
|_file 4 c:\metrics\datatwo.txt
UNIT 4 IS NOW ASSIGNED TO: c:\metrics\datatwo.txt
|_read (4) int intl fields vill rlab plab flab clab wealth cap capmox capmech
6
|           ph om p k cropin fprod sloedit anal depth gender macho heduc &
|           manure man2 tcon mngtl fertl fert /skiplines=1

...SAMPLE RANGE IS NOW SET TO:           1           85
|_genr metre1=anal*.8361
|_genr hectare=metre1/10000
|_genr lmetre1=log(metre1)
|_genr lmetre2=lmetre1**2
|_genr product=fprod/hectare
|_genr lproduct=log(product+1)
|_?stat lproduct/mean=lpri
|_genr lprod1=lproduct/lpri
|_genr lrlab=log(rlab)
|_genr lplab=log(plab)
|_genr lflab=log(flav)
|_genr rflab=rlab/fields
|_genr pflab=plab/fields
|_genr fflab=flab/fields
|_genr lrflab=log(rflab)
|_genr lpflab=log(pflab)
|_genr lfllab=log(fflab)
|_genr lcap=log(cap)
|_genr lcap2=log(cap)
|_genr wealth2=wealth**2
|_genr lwealth=log(wealth)
|_genr capmo2=capmox**2
|_genr capme2=capmech**2
|_genr lcapmo=log(capmox)
|_genr lcapme=log(capmech)
|_genr lcapmo2=lcapmo**2
|_?stat lcapmo2/mean=lca2
|_genr lcap21=lcapmo2/lca2
|_genr lcapme2=lcapme**2
|_genr fertpr1=(fert+1)/hectare
|_genr fertpr2=fertpr1**2
|_genr lfertpr1=log(fertpr1)
|_genr lfertpr2=lfertpr1**2
|_?stat lfertpr1/mean=lf1
|_genr lfert1=lfertpr1/lf1
|_?stat lfertpr2/mean=lf2
|_genr lfert2=lfertpr2/lf2
|_genr sloed2=sloedit**2
|_genr lsloed=log(sloedit)
|_genr lsloed2=lsloed**2
|_?stat lsloed2/mean=ls12
|_genr lslo21=lsloed2/ls12
|_genr soil1=depth
|_?stat om/mean=om1
|_genr om21=om/om1
|_?stat p/mean=p1
|_genr p21=p/p1
|_?stat k /mean=k1
|_genr k21=k/k1
|_genr soil2=om21+p21+k21
|_genr soil3=depth*(om21+p21+k21)
|_genr soil4=depth*(p21+k21)
|_genr soil42=soil4**2
|_genr soil5=depth*ph*(p21+k21)
|_genr soil52=soil5**2
|_genr soil6=depth*ph*(om21+p21+k21)

```

```

|_genr lsoil1=log(soil1)
|_genr lsoil2=log(soil2)
|_genr lsoil3=log(soil3)
|_genr lsoil4=log(soil4)
|_genr lsoil42=lsoil4**2
|_genr lsoil5=log(soil5)
|_genr lsoil52=lsoil5**2
|_genr lsoil6=log(soil6)
|_?stat lsoil5/mean=lso5
|_genr lsoil51=lsoil5/lso5
|_genr cs=capmox*sloedit
|_genr cf=capmox*fertpr1
|_genr c5=capmox*soil5
|_genr sf=sloedit*fertpr1
|_genr s5=sloedit*soil5
|_genr f5=fertpr1*soil5
|_genr lcf=lcapmo*lfertpr1
|_genr lcs=lcapmo*lsloed
|_genr lc5=lcapmo*lsoil5
|_genr lfs=lfertpr1*lsloed
|_genr lf5=lfertpr1*lsoil5
|_genr ls5=lsloed*lsoil5
|_stat product rlab plab flab pflab fflab/pcor

```

NAME	N	MEAN	ST. DEV	VARIANCE	MINIMUM	MAXIMUM
PRODUCT	85	848.26	865.47	0.74904E+06	0.71065	3790.9
RLAB	85	4.2108	1.7502	3.0634	1.0000	10.200
PLAB	85	6.6000	2.4650	6.0762	2.0000	16.000
FLAB	85	4.5882	1.8917	3.5784	1.0000	10.000
RFLAB	85	2.6979	1.6412	2.6936	0.62000	10.045
PFLAB	85	4.2561	2.4902	6.2011	1.0000	16.000
FFLAB	85	2.9271	1.7693	3.1303	0.66667	10.000

CORRELATION MATRIX OF VARIABLES - 85 OBSERVATIONS

PRODUCT	1.0000					
RLAB	-0.61922E-01	1.0000				
PLAB	-0.16564E-01	0.88370	1.0000			
FLAB	0.22141E-01	0.65518	0.80932	1.0000		
RFLAB	-0.97637E-01	0.63845	0.57127	0.36357	1.0000	
PFLAB	-0.82854E-01	0.50356	0.59179	0.43201	0.93323	
FFLAB	1.0000					
	-0.49407E-01	0.38202	0.51519	0.60758	0.78873	
	0.89682	1.0000				
	PRODUCT	RLAB	PLAB	FLAB	RFLAB	
	PFLAB	FFLAB				

NAME	N	MEAN	ST. DEV	VARIANCE	MINIMUM	MAXIMUM
LPRODUCT	85	5.5506	2.2703	5.1542	0.53688	8.2406
LRLAB	85	1.3447	0.45412	0.20623	0.00000	2.3224
LPLAB	85	1.8165	0.38734	0.15003	0.69315	2.7726
LFLAB	85	1.4340	0.44131	0.19475	0.00000	2.3026
LRFLAB	85	0.82481	0.58649	0.34397	-0.47804	2.3071
LPFLAB	85	1.2966	0.56050	0.31416	0.00000	2.7726
LPFLAB	85	0.91408	0.56848	0.32316	-0.40547	2.3026

CORRELATION MATRIX OF VARIABLES - 85 OBSERVATIONS

LPRODUCT	1.0000					
LRLAB	-0.92496E-01	1.0000				
LPLAB	-0.76577E-01	0.85140	1.0000			
LFLAB	-0.11415E-01	0.65655	0.81827	1.0000		
LRFLAB	-0.10504	0.61195	0.52698	0.32328	1.0000	
LPFLAB	-0.87894E-01	0.41849	0.55266	0.37180	0.91473	
LPFLAB	1.0000					
LFFLAB	-0.43345E-01	0.34218	0.49876	0.58534	0.79380	
	0.89804	1.0000				

	LPRODUCT	LRLAB	LPLAB	LFLAB	LRFLAB
_stat product fertpr1 fertpr2/pcor					
NAME	N	MEAN	ST. DEV	VARIANCE	MINIMUM
PRODUCT	85	848.26	865.47	0.74904E+06	0.71065
FERTPR1	85	148.50	129.13	16674.	0.99669
FERTPR2	85	38531.	70402.	0.49564E+10	0.99339

0.51100E+06

CORRELATION MATRIX OF VARIABLES - 85 OBSERVATIONS

	PRODUCT	FERTPR1	FERTPR2
PRODUCT	1.0000		
FERTPR1	0.35127	1.0000	
FERTPR2	0.25373	0.91517	1.0000

	LPRODUCT	lfertpr1	lfertpr2/pcor
NAME	N	MEAN	ST. DEV
LPRODUCT	85	5.5506	2.2703
LFERTPR1	85	4.3355	1.6316
LFERTPR2	85	21.428	10.313

	VARIANCE	MINIMUM	MAXIMUM
LPRODUCT	5.1542	0.53688	8.2406
LFERTPR1	2.6622	-0.33145E-02	6.5721
LFERTPR2	106.37	0.10986E-04	43.192

CORRELATION MATRIX OF VARIABLES - 85 OBSERVATIONS

	LPRODUCT	LFERTPR1	LFERTPR2
LPRODUCT	1.0000		
LFERTPR1	0.25559	1.0000	
LFERTPR2	0.26324	0.96416	1.0000

	LPRODUCT	lfertpr1	lfertpr2/pcor
NAME	N	MEAN	ST. DEV
LPRODUCT	85	5.5506	2.2703
CAPMECH	85	1522.5	1532.2
CAPME2	85	0.46380E+07	0.59253E+07
CAPMOX	85	2899.0	2233.2
CAPMO2	85	0.13333E+08	0.14016E+08

	VARIANCE	MINIMUM	MAXIMUM
LPRODUCT	5.1542	0.53688	8.2406
CAPMECH	0.23477E+07	1.0000	4770.0
CAPME2	0.35109E+14	1.0000	
CAPMOX	0.49873E+07	1.0000	7170.0
CAPMO2	0.19645E+15	1.0000	

0.22753E+08

0.51409E+08

CORRELATION MATRIX OF VARIABLES - 85 OBSERVATIONS

	PRODUCT	CAPMECH	CAPME2	CAPMOX	CAPMO2
PRODUCT	1.0000				
CAPMECH	0.67541E-01	1.0000			
CAPME2	0.79187E-01	0.96289	1.0000		
CAPMOX	0.11748	0.90419	0.85173	1.0000	
CAPMO2	0.89382E-01	0.91888	0.91834	0.95789	1.0000

	LPRODUCT	lcapme	lcapme2	lcapmo	lcapmo2/pcor
NAME	N	MEAN	ST. DEV	VARIANCE	MINIMUM
LPRODUCT	85	5.5506	2.2703	5.1542	0.53688
LCAPME	85	5.9727	2.1871	4.7834	0.00000
LCAPME2	85	40.400	24.326	591.77	0.00000
LCAPMO	85	7.0113	2.0773	4.3153	0.00000
LCAPMO2	85	53.423	23.967	574.44	0.00000

	VARIANCE	MINIMUM	MAXIMUM
LPRODUCT	5.1542	0.53688	8.2406
LCAPME	4.7834	0.00000	8.4701
LCAPME2	591.77	0.00000	71.743
LCAPMO	4.3153	0.00000	8.8777
LCAPMO2	574.44	0.00000	78.813

CORRELATION MATRIX OF VARIABLES - 85 OBSERVATIONS

	LPRODUCT	LCAPME	LCAPME2	LCAPMO	LCAPMO2
LPRODUCT	1.0000				
LCAPME	0.91574E-01	1.0000			
LCAPME2	0.90713E-01	0.98923	1.0000		
LCAPMO	0.15393	0.79215	0.76519	1.0000	
LCAPMO2	0.16493	0.81298	0.80688	0.98643	1.0000

	LPRODUCT	lcapme	lcapme2	lcapmo	lcapmo2/pcor
NAME	N	MEAN	ST. DEV	VARIANCE	MINIMUM
LPRODUCT	85	5.5506	2.2703	5.1542	0.53688
LCAPME	85	5.9727	2.1871	4.7834	0.00000
LCAPME2	85	40.400	24.326	591.77	0.00000
LCAPMO	85	7.0113	2.0773	4.3153	0.00000
LCAPMO2	85	53.423	23.967	574.44	0.00000

	VARIANCE	MINIMUM	MAXIMUM
LPRODUCT	5.1542	0.53688	8.2406
LCAPME	4.7834	0.00000	8.4701
LCAPME2	591.77	0.00000	71.743
LCAPMO	4.3153	0.00000	8.8777
LCAPMO2	574.44	0.00000	78.813

PRODUCT	85	848.26	865.47	0.74904E+06	0.71065	3790.9
SLOEDIT	85	8.3000	3.6032	12.983	1.0000	18.000
SLOED2	85	81.721	68.698	4719.4	1.0000	324.00

CORRELATION MATRIX OF VARIABLES - 85 OBSERVATIONS

PRODUCT	1.0000					
SLOEDIT	-0.45526E-02	1.0000				
SLOED2	-0.27327E-03	0.96452	1.0000			

	PRODUCT	SLOEDIT	SLOED2			
_stat	lproduct	lsloedit	lsloed2/pcor			
NAME	N	MEAN	ST. DEV	VARIANCE	MINIMUM	MAXIMUM
LPRODUCT	85	5.5506	2.2703	5.1542	0.53688	8.2406
LSLOED	85	2.0013	0.53377	0.28491	0.00000	2.8904
LSLOED2	85	4.2867	1.8180	3.3053	0.00000	8.3542

CORRELATION MATRIX OF VARIABLES - 85 OBSERVATIONS

LPRODUCT	1.0000					
LSLOED	-0.85109E-01	1.0000				
LSLOED2	-0.14856	0.95910	1.0000			

	LPRODUCT	LSLOED	LSLOED2					
_stat	product	soil1	soil2	soil3	soil4	soil5	soil6	/pcor
NAME	N	MEAN	ST. DEV	VARIANCE	MINIMUM	MAXIMUM		
PRODUCT	85	848.26	865.47	0.74904E+06	0.71065	3790.9		
SOIL1	85	28.635	8.8369	78.092	15.000	60.000		
SOIL2	85	3.0000	1.2248	1.5002	0.67465	6.2715		
SOIL3	85	85.500	42.597	1814.5	16.866	193.49		
SOIL4	85	56.567	33.421	1116.9	14.534	160.97		
SOIL5	85	284.18	175.40	30763.	82.586	837.41		
SOIL6	85	424.84	212.29	45068.	82.645	985.77		

CORRELATION MATRIX OF VARIABLES - 85 OBSERVATIONS

PRODUCT	1.0000					
SOIL1	0.20918	1.0000				
SOIL2	0.15532	-0.37957E-01	1.0000			
SOIL3	0.23153	0.57535	0.77023	1.0000		
SOIL4	0.35816	0.41886	0.66852	0.79374	1.0000	
SOIL5	0.37452	0.35027	0.66242	0.74329	0.98195	
SOIL6	0.27045	0.50268	0.79787	0.97301	0.82057	

	PRODUCT	SOIL1	SOIL2	SOIL3	SOIL4			
_stat	lproduct	lsoil1	lsoil2	lsoil3	lsoil4	lsoil5	lsoil6	/pcor
NAME	N	MEAN	ST. DEV	VARIANCE	MINIMUM	MAXIMUM		
LPRODUCT	85	5.5506	2.2703	5.1542	0.53688	8.2406		
LSOIL1	85	3.3112	0.29307	0.85892E-01	2.7081	4.0943		
LSOIL2	85	1.0168	0.41463	0.17191	-0.39356	1.8360		
LSOIL3	85	4.3280	0.50227	0.25227	2.8253	5.2652		
LSOIL4	85	3.8855	0.54234	0.29414	2.6765	5.0812		
LSOIL5	85	5.4883	0.56077	0.31447	4.4138	6.7303		
LSOIL6	85	5.9308	0.50292	0.25292	4.4146	6.8934		

CORRELATION MATRIX OF VARIABLES - 85 OBSERVATIONS

LPRODUCT	1.0000				
LSOIL1	0.26592	1.0000			
LSOIL2	0.11181	-0.22777E-01	1.0000		
LSOIL3	0.24746	0.56470	0.81222	1.0000	
LSOIL4	0.38842	0.49291	0.61580	0.79596	1.0000
LSOIL5	0.38392	0.44137	0.59904	0.75206	0.98305


```

      1.0000
LSOIL6 0.25636 0.52457 0.81505 0.97892 0.81267
      0.80601 1.0000
      LPRODUCT LSOIL1 LSOIL2 LSOIL3 LSOIL4
      LSOIL5 LSOIL6

```

```
|_ols product capmox sloedit fertprl soil1
```

```
REQUIRED MEMORY IS PAR= 75 CURRENT PAR= 500
```

```
OLS ESTIMATION
```

```
85 OBSERVATIONS DEPENDENT VARIABLE = PRODUCT
```

```
...NOTE..SAMPLE RANGE SET TO: 1, 85
```

```

R-SQUARE = 0.1926 R-SQUARE ADJUSTED = 0.1523
VARIANCE OF THE ESTIMATE-SIGMA**2 = 0.63498E+06
STANDARD ERROR OF THE ESTIMATE-SIGMA = 796.86
SUM OF SQUARED ERRORS-SSE= 0.50798E+08
MEAN OF DEPENDENT VARIABLE = 848.26
LOG OF THE LIKELIHOOD FUNCTION = -685.890

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```
MODEL SELECTION TESTS - SEE JUDGE ET.AL.(1985, P.242)
```

```
AKAIKE (1969) FINAL PREDICTION ERROR- FPE = 0.67233E+06
```

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(FPE ALSO KNOWN AS AMEMIYA PREDICTION CRITERION -PC)
```

```
AKAIKE (1973) INFORMATION CRITERION- LOG AIC = 13.418
```

```
SCHWARZ (1978) CRITERION-LOG SC = 13.562
```

```
MODEL SELECTION TESTS - SEE RAMANATHAN(1992,P.167)
```

```
CRAVEN-WAHBA(1979) GENERALIZED CROSS VALIDATION(1979) -GCV= 0.67466E+06
```

```
HANNAN AND QUINN(1979) CRITERION -HQ= 0.71224E+06
```

```
RICE (1984) CRITERION-RICE= 0.67731E+06
```

```
SHIBATA (1981) CRITERION-SHIBATA= 0.66794E+06
```

```
SCHWARTZ (1978) CRITERION-SC= 0.77611E+06
```

```
AKAIKE (1974) INFORMATION CRITERION-AIC= 0.67224E+06
```

ANALYSIS OF VARIANCE - FROM MEAN

	SS	DF	MS	F
REGRESSION	0.12121E+08	4.	0.30302E+07	4.772
ERROR	0.50798E+08	80.	0.63498E+06	P-VALUE
TOTAL	0.62919E+08	84.	0.74904E+06	0.002

ANALYSIS OF VARIANCE - FROM ZERO

	SS	DF	MS	F
REGRESSION	0.73282E+08	5.	0.14656E+08	23.082
ERROR	0.50798E+08	80.	0.63498E+06	P-VALUE
TOTAL	0.12408E+09	85.	0.14598E+07	0.000

VARIABLE ELASTICITY	ESTIMATED	STANDARD	T-RATIO	PARTIAL STANDARDIZED
NAME	COEFFICIENT	ERROR	80 DF	P-VALUE CORR. COEFFICIENT AT
MEANS				
CAPMOX	0.20055E-01	0.3943E-01	0.5086	0.612 0.057 0.0517
0.0685				
SLOEDIT	-7.1185	24.23	-0.2938	0.770-0.033 -0.0296 -
0.0697				
FERTPR1	2.5403	0.6837	3.715	0.000 0.384 0.3790
0.4447				
SOIL1	24.950	10.03	2.486	0.015 0.268 0.2548
0.8422				
CONSTANT	-242.48	375.6	-0.6455	0.520-0.072 0.0000 -
0.2859				

```
|_ols product capmox sloedit fertprl soil4
```

```
REQUIRED MEMORY IS PAR= 75 CURRENT PAR= 500
```

```
OLS ESTIMATION
```

```
85 OBSERVATIONS DEPENDENT VARIABLE = PRODUCT
```

```
...NOTE..SAMPLE RANGE SET TO: 1, 85
```

R-SQUARE = 0.2366 R-SQUARE ADJUSTED = 0.1984
 VARIANCE OF THE ESTIMATE-SIGMA**2 = 0.60044E+06
 STANDARD ERROR OF THE ESTIMATE-SIGMA = 774.88
 SUM OF SQUARED ERRORS-SSE= 0.48035E+08
 MEAN OF DEPENDENT VARIABLE = 848.26
 LOG OF THE LIKELIHOOD FUNCTION = -683.514

MODEL SELECTION TESTS - SEE JUDGE ET.AL.(1985, P.242)
 AKAIKE (1969) FINAL PREDICTION ERROR- FPE = 0.63576E+06
 (FPE ALSO KNOWN AS AMEMIYA PREDICTION CRITERION -PC)
 AKAIKE (1973) INFORMATION CRITERION- LOG AIC = 13.362
 SCHWARZ(1978) CRITERION-LOG SC = 13.506
 MODEL SELECTION TESTS - SEE RAMANATHAN(1992,P.167)
 CRAVEN-WAHBA(1979) GENERALIZED CROSS VALIDATION(1979) -GCV= 0.63797E+06
 HANNAN AND QUINN(1979) CRITERION -HQ= 0.67349E+06
 RICE (1984) CRITERION-RICE= 0.64047E+06
 SHIBATA (1981) CRITERION-SHIBATA= 0.63161E+06
 SCHWARTZ (1978) CRITERION-SC= 0.73390E+06
 AKAIKE (1974) INFORMATION CRITERION-AIC= 0.63567E+06

ANALYSIS OF VARIANCE - FROM MEAN				
	SS	DF	MS	F
REGRESSION	0.14884E+08	4.	0.37210E+07	6.197
ERROR	0.48035E+08	80.	0.60044E+06	P-VALUE
TOTAL	0.62919E+08	84.	0.74904E+06	0.000

ANALYSIS OF VARIANCE - FROM ZERO				
	SS	DF	MS	F
REGRESSION	0.76045E+08	5.	0.15209E+08	25.330
ERROR	0.48035E+08	80.	0.60044E+06	P-VALUE
TOTAL	0.12408E+09	85.	0.14598E+07	0.000

VARIABLE	ESTIMATED	STANDARD	T-RATIO	PARTIAL STANDARDIZED		
ELASTICITY						
NAME	COEFFICIENT	ERROR	80 DF	P-VALUE	CORR. COEFFICIENT	AT
MEANS						
CAPMOX	0.37113E-01	0.3808E-01	0.9745	0.333	0.108	0.0958
0.1268						
SLOEDIT	-10.764	23.62	-0.4557	0.650-0.051	-0.0448	-
0.1053						
FERTPR1	2.0349	0.6629	3.070	0.003	0.325	0.3036
0.3562						
SOIL4	8.5645	2.566	3.338	0.001	0.350	0.3307
0.5711						
CONSTANT	43.360	279.2	0.1553	0.877	0.017	0.0000
0.0511						

|_ols product capmox sloedit fertpr1 soil5

REQUIRED MEMORY IS PAR= 75 CURRENT PAR= 500
 OLS ESTIMATION
 85 OBSERVATIONS DEPENDENT VARIABLE = PRODUCT
 ...NOTE...SAMPLE RANGE SET TO: 1, 85

R-SQUARE = 0.2441 R-SQUARE ADJUSTED = 0.2063
 VARIANCE OF THE ESTIMATE-SIGMA**2 = 0.59454E+06
 STANDARD ERROR OF THE ESTIMATE-SIGMA = 771.06
 SUM OF SQUARED ERRORS-SSE= 0.47563E+08
 MEAN OF DEPENDENT VARIABLE = 848.26
 LOG OF THE LIKELIHOOD FUNCTION = -683.094

MODEL SELECTION TESTS - SEE JUDGE ET.AL.(1985, P.242)
 AKAIKE (1969) FINAL PREDICTION ERROR- FPE = 0.62951E+06
 (FPE ALSO KNOWN AS AMEMIYA PREDICTION CRITERION -PC)
 AKAIKE (1973) INFORMATION CRITERION- LOG AIC = 13.353
 SCHWARZ(1978) CRITERION-LOG SC = 13.496

MODEL SELECTION TESTS - SEE RAMANATHAN(1992,P.167)
 CRAVEN-WAHBA(1979) GENERALIZED CROSS VALIDATION(1979) -GCV= 0.63170E+06
 HANNAN AND QUINN(1979) CRITERION -HQ= 0.66688E+06
 RICE (1984) CRITERION-RICE= 0.63418E+06
 SHIBATA (1981) CRITERION-SHIBATA= 0.62540E+06
 SCHWARTZ (1978) CRITERION-SC= 0.72669E+06
 AKAIKE (1974) INFORMATION CRITERION-AIC= 0.62943E+06

	SS	DF	MS	F
REGRESSION	0.15356E+08	4.	0.38390E+07	6.457
ERROR	0.47563E+08	80.	0.59454E+06	P-VALUE
TOTAL	0.62919E+08	84.	0.74904E+06	0.000

	SS	DF	MS	F
REGRESSION	0.76517E+08	5.	0.15303E+08	25.740
ERROR	0.47563E+08	80.	0.59454E+06	P-VALUE
TOTAL	0.12408E+09	85.	0.14598E+07	0.000

VARIABLE ELASTICITY	ESTIMATED	STANDARD	T-RATIO	PARTIAL	STANDARDIZED
NAME	COEFFICIENT	ERROR	80 DF	P-VALUE	CORR. COEFFICIENT AT
MEANS					
CAPMOX	0.41172E-01	0.3796E-01	1.085	0.281	0.120 0.1062
0.1407					
SLOEDIT	-11.050	23.51	-0.4701	0.640	-0.052 -0.0460 -
0.1081					
FERTPR1	1.9569	0.6623	2.955	0.004	0.314 0.2920
0.3426					
SOIL5	1.6971	0.4890	3.470	0.001	0.362 0.3439
0.5685					
CONSTANT	47.756	275.7	0.1732	0.863	0.019 0.0000
0.0563					

|_ols product capmox capmo2 sloedit sloed2 fertpr1 fertpr2 soil5 soil52 cs cf
 c5 sf s5 f5

REQUIRED MEMORY IS PAR= 82 CURRENT PAR= 500
 OLS ESTIMATION
 85 OBSERVATIONS DEPENDENT VARIABLE = PRODUCT
 ...NOTE..SAMPLE RANGE SET TO: 1, 85
 R-SQUARE = 0.3608 R-SQUARE ADJUSTED = 0.2329
 VARIANCE OF THE ESTIMATE-SIGMA**2 = 0.57455E+06
 STANDARD ERROR OF THE ESTIMATE-SIGMA = 757.99
 SUM OF SQUARED ERRORS-SSE= 0.40219E+08
 MEAN OF DEPENDENT VARIABLE = 848.26
 LOG OF THE LIKELIHOOD FUNCTION = -675.965

MODEL SELECTION TESTS - SEE JUDGE ET.AL.(1985, P.242)
 AKAIKE (1969) FINAL PREDICTION ERROR- FPE = 0.67595E+06
 (FPE ALSO KNOWN AS AMEMIYA PREDICTION CRITERION -PC)
 AKAIKE (1973) INFORMATION CRITERION- LOG AIC = 13.420
 SCHWARZ(1978) CRITERION-LOG SC = 13.851
 MODEL SELECTION TESTS - SEE RAMANATHAN(1992,P.167)
 CRAVEN-WAHBA(1979) GENERALIZED CROSS VALIDATION(1979) -GCV= 0.69767E+06
 HANNAN AND QUINN(1979) CRITERION -HQ= 0.80092E+06
 RICE (1984) CRITERION-RICE= 0.73125E+06
 SHIBATA (1981) CRITERION-SHIBATA= 0.64016E+06
 SCHWARTZ (1978) CRITERION-SC= 0.10363E+07
 AKAIKE (1974) INFORMATION CRITERION-AIC= 0.67343E+06

ANALYSIS OF VARIANCE - FROM MEAN				
	SS	DF	MS	F
REGRESSION	0.22700E+08	14.	0.16215E+07	2.822
ERROR	0.40219E+08	70.	0.57455E+06	P-VALUE
TOTAL	0.62919E+08	84.	0.74904E+06	0.002

ANALYSIS OF VARIANCE - FROM ZERO				
	SS	DF	MS	F
REGRESSION	0.83862E+08	15.	0.55908E+07	9.731
ERROR	0.40219E+08	70.	0.57455E+06	P-VALUE
TOTAL	0.12408E+09	85.	0.14598E+07	0.000

VARIABLE ELASTICITY	ESTIMATED	STANDARD	T-RATIO	PARTIAL STANDARDIZED		
NAME	COEFFICIENT	ERROR	70 DF	P-VALUE	CORR. COEFFICIENT	AT
MEANS						
CAPMOX	0.13379	0.1719	0.7785	0.439	0.093	0.3452
0.4572						
CAPMO2	-0.43507E-04	0.2303E-04	-1.889	0.063	-0.220	-0.7046 -
0.6838						
SLOEDIT	-179.99	102.1	-1.763	0.082	-0.206	-0.7493 -
1.7611						
SLOED2	5.0622	4.998	1.013	0.315	0.120	0.4018
0.4877						
FERTPR1	-1.3689	2.890	-0.4737	0.637	-0.057	-0.2042 -
0.2397						
FERTPR2	-0.40777E-02	0.3374E-02	-1.208	0.231	-0.143	-0.3317 -
0.1852						
SOIL5	-0.27455	3.064	-0.8959E-01	0.929	-0.011	-0.0556 -
0.0920						
SOIL52	0.50241E-04	0.2544E-02	0.1975E-01	0.984	0.002	0.0085
0.0066						
CS	0.99221E-02	0.1087E-01	0.9129	0.364	0.108	0.2602
0.2804						
CF	0.47679E-03	0.3631E-03	1.313	0.193	0.155	0.3552
0.2581						
C5	0.97360E-04	0.2337E-03	0.4166	0.678	0.050	0.1003
0.0921						
SF	0.16690	0.1952	0.8549	0.396	0.102	0.2670
0.2435						
S5	0.91027E-01	0.2130	0.4273	0.670	0.051	0.1965
0.2608						
F5	0.72650E-02	0.3509E-02	2.071	0.042	0.240	0.4989
0.3888						
CONSTANT	1261.0	782.3	1.612	0.111	0.189	0.0000
1.4866						

|_ols lproduct lcapmo2 lfertpr1 lsloed2 lsoil1

REQUIRED MEMORY IS PAR= 75 CURRENT PAR= 500
 OLS ESTIMATION
 85 OBSERVATIONS DEPENDENT VARIABLE = LPRODUCT
 ...NOTE...SAMPLE RANGE SET TO: 1, 85

R-SQUARE = 0.1895 R-SQUARE ADJUSTED = 0.1490
 VARIANCE OF THE ESTIMATE-SIGMA**2 = 4.3863
 STANDARD ERROR OF THE ESTIMATE-SIGMA = 2.0943
 SUM OF SQUARED ERRORS-SSE= 350.90
 MEAN OF DEPENDENT VARIABLE = 5.5506
 LOG OF THE LIKELIHOOD FUNCTION = -180.868

MODEL SELECTION TESTS - SEE JUDGE ET.AL.(1985, P.242)
 AKAIKE (1969) FINAL PREDICTION ERROR- FPE = 4.6443
 (FPE ALSO KNOWN AS AHAMIYA PREDICTION CRITERION -PC)
 AKAIKE (1973) INFORMATION CRITERION- LOG AIC = 1.5355
 SCHWARZ(1978) CRITERION-LOG SC = 1.6792

MODEL SELECTION TESTS - SEE RAMANATHAN(1992,P.167)
 CRAVEN-WAHBA(1979) GENERALIZED CROSS VALIDATION(1979) -GCV= 4.6604
 HANNAN AND QUINN(1979) CRITERION -HQ= 4.9199
 RICE (1984) CRITERION-RICE= 4.6787
 SHIBATA (1981) CRITERION-SHIBATA= 4.6139
 SCHWARTZ (1978) CRITERION-SC= 5.3612
 AKAIKE (1974) INFORMATION CRITERION-AIC= 4.6436

	SS	DF	MS	F
REGRESSION	82.051	4.	20.513	4.677
ERROR	350.90	80.	4.3863	P-VALUE
TOTAL	432.95	84.	5.1542	0.002

	SS	DF	MS	F
REGRESSION	2700.8	5.	540.16	123.149
ERROR	350.90	80.	4.3863	P-VALUE
TOTAL	3051.7	85.	35.903	0.000

VARIABLE ELASTICITY NAME	ESTIMATED COEFFICIENT	STANDARD ERROR	T-RATIO 80 DF	P-VALUE	PARTIAL CORR.	STANDARDIZED COEFFICIENT	AT
MEANS							
LCAPMO2	0.12891E-01	0.9637E-02	1.338	0.185	0.148	0.1361	
0.1241							
LFERTPR1	0.34750	0.1436	2.420	0.018	0.261	0.2497	
0.2714							
LSLOED2	-0.18252	0.1275	-1.431	0.156	-0.158	-0.1462	-
0.1410							
LSOIL1	2.3749	0.7868	3.019	0.003	0.320	0.3066	
1.4167							
CONSTANT	-3.7261	2.798	-1.332	0.187	-0.147	0.0000	-
0.6713							

|_ols lproduct lcapmo2 lfertpr1 lsloed2 lsoil4

REQUIRED MEMORY IS PAR= 75 CURRENT PAR= 500
 OLS ESTIMATION
 85 OBSERVATIONS DEPENDENT VARIABLE = LPRODUCT
 ...NOTE..SAMPLE RANGE SET TO: 1, 85

R-SQUARE = 0.2776 R-SQUARE ADJUSTED = 0.2415
 VARIANCE OF THE ESTIMATE-SIGMA**2 = 3.9093
 STANDARD ERROR OF THE ESTIMATE-SIGMA = 1.9772
 SUM OF SQUARED ERRORS-SSE= 312.75
 MEAN OF DEPENDENT VARIABLE = 5.5506
 LOG OF THE LIKELIHOOD FUNCTION = -175.976

MODEL SELECTION TESTS - SEE JUDGE ET.AL.(1985, P.242)
 AKAIKE (1969) FINAL PREDICTION ERROR- FPE = 4.1393
 (FPE ALSO KNOWN AS AMEMIYA PREDICTION CRITERION -PC)
 AKAIKE (1973) INFORMATION CRITERION- LOG AIC = 1.4204
 SCHWARZ(1978) CRITERION-LOG SC = 1.5641
 MODEL SELECTION TESTS - SEE RAMANATHAN(1992,P.167)
 CRAVEN-WAHBA(1979) GENERALIZED CROSS VALIDATION(1979) -GCV= 4.1537
 HANNAN AND QUINN(1979) CRITERION -HQ= 4.3850
 RICE (1984) CRITERION-RICE= 4.1700
 SHIBATA (1981) CRITERION-SHIBATA= 4.1123
 SCHWARTZ (1978) CRITERION-SC= 4.7783
 AKAIKE (1974) INFORMATION CRITERION-AIC= 4.1387

ANALYSIS OF VARIANCE - FROM MEAN				
	SS	DF	MS	F
REGRESSION	120.20	4.	30.051	7.687
ERROR	312.75	80.	3.9093	P-VALUE
TOTAL	432.95	84.	5.1542	0.000

ANALYSIS OF VARIANCE - FROM ZERO				
	SS	DF	MS	F
REGRESSION	2739.0	5.	547.79	140.124
ERROR	312.75	80.	3.9093	P-VALUE
TOTAL	3051.7	85.	35.903	0.000

VARIABLE ELASTICITY	ESTIMATED	STANDARD	T-RATIO	PARTIAL STANDARDIZED		
NAME	COEFFICIENT	ERROR	80 DF	P-VALUE	CORR. COEFFICIENT	AT
MEANS						
LCAPMO2	0.16976E-01	0.9138E-02	1.858	0.067	0.203	0.1792
0.1634						
LFERTPR1	0.26843	0.1352	1.986	0.050	0.217	0.1929
0.2097						
LSLOED2	-0.25422	0.1222	-2.081	0.041	-0.227	-0.2036
0.1963						
LSOIL4	1.8162	0.4063	4.470	0.000	0.447	0.4339
1.2714						
CONSTANT	-2.4873	1.759	-1.414	0.161	-0.156	0.0000
0.4481						

|_ols lproduct lcapmo2 lfertpr1 lsloed2 lsoil5

REQUIRED MEMORY IS PAR= 75 CURRENT PAR= 500
 OLS ESTIMATION
 85 OBSERVATIONS DEPENDENT VARIABLE = LPRODUCT
 ...NOTE...SAMPLE RANGE SET TO: 1, 85

R-SQUARE = 0.2747 R-SQUARE ADJUSTED = 0.2384
 VARIANCE OF THE ESTIMATE-SIGMA**2 = 3.9253
 STANDARD ERROR OF THE ESTIMATE-SIGMA = 1.9812
 SUM OF SQUARED ERRORS-SSE= 314.02
 MEAN OF DEPENDENT VARIABLE = 5.5506
 LOG OF THE LIKELIHOOD FUNCTION = -176.150

MODEL SELECTION TESTS - SEE JUDGE ET.AL.(1985, P.242)
 AKAIKE (1969) FINAL PREDICTION ERROR- FPE = 4.1562
 (FPE ALSO KNOWN AS AMEMIYA PREDICTION CRITERION -PC)
 AKAIKE (1973) INFORMATION CRITERION- LOG AIC = 1.4245
 SCHWARZ(1978) CRITERION-LOG SC = 1.5682
 MODEL SELECTION TESTS - SEE RAMANATHAN(1992,P.167)
 CRAVEN-WAHBA(1979) GENERALIZED CROSS VALIDATION(1979) -GCV= 4.1706
 HANNAN AND QUINN(1979) CRITERION -HQ= 4.4029
 RICE (1984) CRITERION-RICE= 4.1870
 SHIBATA (1981) CRITERION-SHIBATA= 4.1290
 SCHWARTZ (1978) CRITERION-SC= 4.7978
 AKAIKE (1974) INFORMATION CRITERION-AIC= 4.1556

ANALYSIS OF VARIANCE - FROM MEAN				
	SS	DF	MS	F
REGRESSION	118.93	4.	29.732	7.574
ERROR	314.02	80.	3.9253	P-VALUE
TOTAL	432.95	84.	5.1542	0.000

ANALYSIS OF VARIANCE - FROM ZERO				
	SS	DF	MS	F
REGRESSION	2737.7	5.	547.54	139.489
ERROR	314.02	80.	3.9253	P-VALUE
TOTAL	3051.7	85.	35.903	0.000

VARIABLE ELASTICITY NAME	ESTIMATED COEFFICIENT	STANDARD ERROR	T-RATIO 80 DF	P-VALUE	PARTIAL CORR. COEFFICIENT	STANDARDIZED AT
MEANS						
LCAPMO2	0.17599E-01	0.9171E-02	1.919	0.059	0.210	0.1858
0.1694						
LFERTPR1	0.26443	0.1355	1.951	0.055	0.213	0.1900
0.2065						
LSLOED2	-0.25260	0.1224	-2.064	0.042	-0.225	-0.2023
0.1951						
L5OIL5	1.7444	0.3943	4.424	0.000	0.443	0.4309
1.7248						
CONSTANT	-5.0269	2.281	-2.204	0.030	-0.239	0.0000
0.9057						

|_ols lproduct lcapmo lcapmo2 lsloed lsloed2 lsol5 lsol52 lfertpr1 lfertpr2
lcs lc5 lcf ls5 lfs lf5

REQUIRED MEMORY IS PAR= 82 CURRENT PAR= 500
OLS ESTIMATION
85 OBSERVATIONS DEPENDENT VARIABLE = LPRODUCT
...NOTE..SAMPLE RANGE SET TO: 1, 85

R-SQUARE = 0.3717 R-SQUARE ADJUSTED = 0.2460
VARIANCE OF THE ESTIMATE-SIGMA**2 = 3.8863
STANDARD ERROR OF THE ESTIMATE-SIGMA = 1.9714
SUM OF SQUARED ERRORS-SSE= 272.04
MEAN OF DEPENDENT VARIABLE = 5.5506
LOG OF THE LIKELIHOOD FUNCTION = -170.050

MODEL SELECTION TESTS - SEE JUDGE ET.AL.(1985, P.242)
AKAIKE (1969) FINAL PREDICTION ERROR- FPE = 4.5722
(FPE ALSO KNOWN AS AMEMIYA PREDICTION CRITERION -PC)
AKAIKE (1973) INFORMATION CRITERION- LOG AIC = 1.5163
SCHWARZ(1978) CRITERION-LOG SC = 1.9473
MODEL SELECTION TESTS - SEE RAMANATHAN(1992,P.167)
CRAVEN-WAHBA(1979) GENERALIZED CROSS VALIDATION(1979) -GCV= 4.7191
HANNAN AND QUINN(1979) CRITERION -HQ= 5.4175
RICE (1984) CRITERION-RICE= 4.9462
SHIBATA (1981) CRITERION-SHIBATA= 4.3301
SCHWARTZ (1978) CRITERION-SC= 7.0098
AKAIKE (1974) INFORMATION CRITERION-AIC= 4.5551

	ANALYSIS OF VARIANCE - FROM MEAN			
	SS	DF	MS	F
REGRESSION	160.91	14.	11.493	2.957
ERROR	272.04	70.	3.8863	P-VALUE
TOTAL	432.95	84.	5.1542	0.001

	ANALYSIS OF VARIANCE - FROM ZERO			
	SS	DF	MS	F
REGRESSION	2779.7	15.	185.31	47.683
ERROR	272.04	70.	3.8863	P-VALUE
TOTAL	3051.7	85.	35.903	0.000

VARIABLE ELASTICITY	ESTIMATED	STANDARD	T-RATIO	PARTIAL STANDARDIZED		
NAME	COEFFICIENT	ERROR	70 DF	P-VALUE	CORR. COEFFICIENT	AT
MEANS						
LCAPMO	0.93227	1.316	0.7086	0.481	0.084	0.8530
1.1776						
LCAPMO2	0.33662E-01	0.5831E-01	0.5772	0.566	0.069	0.3554
0.3240						
LSLOED	-10.633	5.814	-1.829	0.072	0.214	-2.5000 -
3.8339						
LSLOED2	-1.2352	0.5101	-2.422	0.018	0.278	-0.9892 -
0.9540						
LSOIL5	5.0619	7.975	0.6347	0.528	0.076	1.2503
5.0051						
LSOIL52	-0.40118	0.6723	-0.5967	0.553	0.071	-1.1061 -
2.1995						
LFERTPR1	-1.0970	1.501	-0.7309	0.467	0.087	-0.7884 -
0.8569						
LFERTPR2	0.37823E-01	0.8537E-01	0.4430	0.659	0.053	0.1718
0.1460						
LCS	0.25933	0.2683	0.9667	0.337	0.115	0.6611
0.6563						
LC5	-0.39312	0.2292	-1.715	0.091	0.201	-2.0606 -
2.7178						
LCF	0.13822	0.7478E-01	1.848	0.069	0.216	0.9121
0.7687						
LS5	2.0850	1.160	1.798	0.077	0.210	2.9659
4.1498						
LFS	0.24409	0.2902	0.8412	0.403	0.100	0.4401
0.3773						
LF5	-0.69489E-01	0.2331	-0.2981	0.767	0.036	-0.2913 -
0.2982						
CONSTANT	-4.1325	25.53	-0.1619	0.872	0.019	0.0000 -
0.7445						

|_stat lfertpr1 lcapho2 lsloed2 lsoil1 lsoil4 lsoil5/pcor

NAME	N	MEAN	ST. DEV	VARIANCE	MINIMUM	MAXIMUM
LFERTPR1	85	4.3355	1.6316	2.6622	-0.33145E-02	6.5721
LCAPMO2	85	53.423	23.967	574.44	0.00000	78.813
LSLOED2	85	4.2867	1.8180	3.3053	0.00000	8.3542
LSOIL1	85	3.3112	0.29307	0.85892E-01	2.7081	4.0943
LSOIL4	85	3.8855	0.54234	0.29414	2.6765	5.0812
LSOIL5	85	5.4883	0.56077	0.31447	4.4138	6.7303

CORRELATION MATRIX OF VARIABLES -

85 OBSERVATIONS

LFERTPR1	1.0000					
LCAPMO2	0.13586	1.0000				
LSLOED2	-0.14068	0.32799E-01	1.0000			
LSOIL1	-0.10831	-0.98638E-03	0.92204E-01	1.0000		
LSOIL4	0.22320E-01	-0.77959E-01	0.17581	0.49291	1.0000	
LSOIL5	0.27496E-01	-0.92951E-01	0.17258	0.44137	0.98305	

1.0000

LFERTPR1 LCAPMO2 LSLOED2 LSOIL1 LSOIL4
LSOIL5

|_stat fertpr1 capmox wealth sloedit/pcor

NAME	N	MEAN	ST. DEV	VARIANCE	MINIMUM	MAXIMUM
FERTPR1	85	148.50	129.13	16674.	0.99669	714.84
CAPMOX	85	2899.0	2233.2	0.49873E+07	1.0000	7170.0
WEALTH	85	5933.2	4676.9	0.21873E+08	695.00	24195.
SLOEDIT	85	8.3000	3.6032	12.983	1.0000	18.000

CORRELATION MATRIX OF VARIABLES -

85 OBSERVATIONS

FERTPR1	1.0000			
CAPMOX	0.10068	1.0000		
WEALTH	0.15754	0.59753	1.0000	
SLOEDIT	0.10401E-01	-0.11641E-01	-0.95600E-01	1.0000
	FERTPR1	CAPMOX	WEALTH	SLOEDIT

|_stat fertpr1 p k om ph/pcor

NAME	N	MEAN	ST. DEV	VARIANCE	MINIMUM	MAXIMUM
FERTPR1	85	148.50	129.13	16674.	0.99669	714.84
P	85	10.569	9.9582	99.166	0.10000E-02	49.270
K	85	112.15	49.329	2433.3	38.000	261.00
OM	85	2.0997	1.6271	2.6476	0.10000E-02	9.0600
PH	85	4.9936	0.53214	0.28318	4.1600	6.5800

CORRELATION MATRIX OF VARIABLES -

85 OBSERVATIONS

FERTPR1	1.0000				
P	0.16421	1.0000			
K	0.15775	0.14995	1.0000		
OM	-0.73832E-01	-0.24812	0.82721E-01	1.0000	
PH	0.58299E-01	0.94745E-01	0.33324	-0.21337	1.0000
	FERTPR1	P	K	OM	PH

|_pols lsoil4 lfertpr1

|_test lfertpr1

TEST VALUE = 0.74190E-02 STD. ERROR OF TEST VALUE 0.36476E-01
 T STATISTIC = 0.20339695 WITH 83 D.F. P-VALUE= 0.83932
 F STATISTIC = 0.41370317E-01 WITH 1 AND 83 D.F. P-VALUE= 0.83932
 WALD CHI-SQUARE STATISTIC = 0.41370317E-01 WITH 1 D.F. P-VALUE= 0.83882
 UPPER BOUND ON P-VALUE BY CHEBYCHEV INEQUALITY = 1.00000

|_pols lsoil4 lfertpr2

|_test lfertpr2

TEST VALUE = 0.34175E-02 STD. ERROR OF TEST VALUE 0.57598E-02
 T STATISTIC = 0.59333171 WITH 83 D.F. P-VALUE= 0.55457
 F STATISTIC = 0.35204252 WITH 1 AND 83 D.F. P-VALUE= 0.55457
 WALD CHI-SQUARE STATISTIC = 0.35204252 WITH 1 D.F. P-VALUE= 0.55296
 UPPER BOUND ON P-VALUE BY CHEBYCHEV INEQUALITY = 1.00000

|_pols lsoil4 lsloed2

|_test lsloed2

TEST VALUE = 0.52446E-01 STD. ERROR OF TEST VALUE 0.32234E-01
 T STATISTIC = 1.6270510 WITH 83 D.F. P-VALUE= 0.10752
 F STATISTIC = 2.6472951 WITH 1 AND 83 D.F. P-VALUE= 0.10752
 WALD CHI-SQUARE STATISTIC = 2.6472951 WITH 1 D.F. P-VALUE= 0.10373
 UPPER BOUND ON P-VALUE BY CHEBYCHEV INEQUALITY = 0.37774

|_pols lsoil5 lfertpr1

|_test lfertpr1

TEST VALUE = 0.94501E-02 STD. ERROR OF TEST VALUE 0.37710E-01
 T STATISTIC = 0.25059803 WITH 83 D.F. P-VALUE= 0.80274
 F STATISTIC = 0.62799372E-01 WITH 1 AND 83 D.F. P-VALUE= 0.80274
 WALD CHI-SQUARE STATISTIC = 0.62799372E-01 WITH 1 D.F. P-VALUE= 0.80212
 UPPER BOUND ON P-VALUE BY CHEBYCHEV INEQUALITY = 1.00000

|_pols lsoil5 lfertpr2

|_test lfertpr2

TEST VALUE = 0.39737E-02 STD. ERROR OF TEST VALUE 0.59522E-02
 T STATISTIC = 0.66760390 WITH 83 D.F. P-VALUE= 0.50624
 F STATISTIC = 0.44569497 WITH 1 AND 83 D.F. P-VALUE= 0.50624
 WALD CHI-SQUARE STATISTIC = 0.44569497 WITH 1 D.F. P-VALUE= 0.50439
 UPPER BOUND ON P-VALUE BY CHEBYCHEV INEQUALITY = 1.00000

|_pols lsoil5 lsloed2

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|_test lsloed2
TEST VALUE = 0.53233E-01 STD. ERROR OF TEST VALUE 0.33349E-01
T STATISTIC = 1.5962673 WITH 83 D.F. P-VALUE= 0.11423
F STATISTIC = 2.5480694 WITH 1 AND 83 D.F. P-VALUE= 0.11423
WALD CHI-SQUARE STATISTIC = 2.5480694 WITH 1 D.F. P-VALUE= 0.11043
UPPER BOUND ON P-VALUE BY CHEBYCHEV INEQUALITY = 0.39245
|_?ols lfertpr1 lcapmo2 lsloed2
|_test
|_test lcapmo2=0
|_test lsloed2=0
|_end
F STATISTIC = 1.6880883 WITH 2 AND 82 D.F. P-VALUE= 0.19123
WALD CHI-SQUARE STATISTIC = 3.3761766 WITH 2 D.F. P-VALUE= 0.18487
UPPER BOUND ON P-VALUE BY CHEBYCHEV INEQUALITY = 0.59239
|_?ols lsol15 lfertpr1 lcapmo2 lsloed2
|_test
|_test lfertpr1=0
|_test lcapmo2=0
|_test lsloed2=0
|_end
F STATISTIC = 1.2428656 WITH 3 AND 81 D.F. P-VALUE= 0.29966
WALD CHI-SQUARE STATISTIC = 3.7285969 WITH 3 D.F. P-VALUE= 0.29230
UPPER BOUND ON P-VALUE BY CHEBYCHEV INEQUALITY = 0.80459
|_?ols lsol14 lfertpr1 lcapmo2 lsloed2
|_test
|_test lfertpr1=0
|_test lcapmo2=0
|_test lsloed2=0
|_end
F STATISTIC = 1.1698897 WITH 3 AND 81 D.F. P-VALUE= 0.32641
WALD CHI-SQUARE STATISTIC = 3.5096691 WITH 3 D.F. P-VALUE= 0.31951
UPPER BOUND ON P-VALUE BY CHEBYCHEV INEQUALITY = 0.85478
|_stat lcapmo2 lsloed2 lfertpr1 lsol11 lsol14 lsol15/pcor
NAME N MEAN ST. DEV VARIANCE MINIMUM MAXIMUM
LCAPMO2 85 53.423 23.967 574.44 0.00000 78.813
LSLOED2 85 4.2867 1.8180 3.3053 0.00000 8.3542
LFERTPR1 85 4.3355 1.6316 2.6622 -0.33145E-02 6.5721
LSOIL1 85 3.3112 0.29307 0.85892E-01 2.7081 4.0943
LSOIL4 85 3.8855 0.54234 0.29414 2.6765 5.0812
LSOIL5 85 5.4883 0.56077 0.31447 4.4138 6.7303

CORRELATION MATRIX OF VARIABLES - 85 OBSERVATIONS

LCAPMO2 1.0000
LSLOED2 0.32799E-01 1.0000
LFERTPR1 0.13586 -0.14068 1.0000
LSOIL1 -0.98638E-03 0.92204E-01 -0.10831 1.0000
LSOIL4 -0.77959E-01 0.17581 0.22320E-01 0.49291 1.0000
LSOIL5 -0.92951E-01 0.17258 0.27496E-01 0.44137 0.98305
1.0000
LCAPMO2 LSLOED2 LFERTPR1 LSOIL1 LSOIL4
LSOIL5

|_sort gender product lproduct lcapmo2 lfertpr1 lsloed2 lsol15 soil5
DATA HAS BEEN SORTED BY VARIABLE GENDER
|_smpl 1 28
|_stat gender product soil5
NAME N MEAN ST. DEV VARIANCE MINIMUM MAXIMUM
GENDER 28 1.0000 0.00000 0.00000 1.0000 1.0000
PRODUCT 28 774.15 729.52 0.53220E+06 1.6765 2496.5
SOIL5 28 276.37 167.54 28069. 96.549 663.41
|_?ols lproduct lcapmo2 lfertpr1 lsloed2 lsol15
|_gen1 ssel=$sse
..NOTE..CURRENT VALUE OF $SSE = 85.203
|_smpl 58 85
|_stat gender product soil5

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NAME      N      MEAN      ST. DEV      VARIANCE      MINIMUM      MAXIMUM
GENDER    28      2.0000      0.00000      0.00000      2.0000      2.0000
PRODUCT   28      841.66      1004.6      0.10092E+07  0.71065      3790.9
SOIL5     28      296.40      195.36      38164.      82.586      787.16
|_?ols lproduct lcapmo2 lfertpr1 lsloed2 lsoil5
|_gen1 sse2=$sse
..NOTE..CURRENT VALUE OF $SSE = 95.174
|_gen1 GQgender=sse2/sse1
|_print GQgender
      GQGENDER
      1.117026
|_smpl 1 85
|_sort int wealth product lproduct lcapmo2 lfertpr1 lsloed2 lsoil5 soil5
DATA HAS BEEN SORTED BY VARIABLE INT
|_sort wealth product lproduct lcapmo2 lfertpr1 lsloed2 lsoil5 soil5
DATA HAS BEEN SORTED BY VARIABLE WEALTH
|_smpl 1 35
|_stat wealth product soil5
NAME      N      MEAN      ST. DEV      VARIANCE      MINIMUM      MAXIMUM
WEALTH    35      2083.1      933.38      0.87120E+06  695.00      4010.0
PRODUCT   35      715.70      687.29      0.47237E+06  1.0072      2150.2
SOIL5     35      267.16      152.70      23319.      82.586      837.41
|_?ols lproduct lcapmo2 lfertpr1 lsloed2 lsoil5
|_gen1 sse1=$sse
..NOTE..CURRENT VALUE OF $SSE = 56.732
|_smpl 51 85
|_stat wealth product soil5
NAME      N      MEAN      ST. DEV      VARIANCE      MINIMUM      MAXIMUM
WEALTH    35      10086.      4444.5      0.19754E+08  6295.0      24195.
PRODUCT   35      937.98      917.16      0.84118E+06  0.71065      2739.2
SOIL5     35      298.14      196.44      38589.      96.549      787.16
|_?ols lproduct lcapmo2 lfertpr1 lsloed2 lsoil5
|_gen1 sse2=$sse
..NOTE..CURRENT VALUE OF $SSE = 161.06
|_gen1 GQwealth=sse2/sse1
|_print GQwealth
      GQWEALTH
      2.838972
|_smpl 1 85
|_genr wgt=1/wealth

|_ols lproduct lcapmo2 lfertpr1 lsloed2 lsoil1/ weight=wgt anova

REQUIRED MEMORY IS PAR= 76 CURRENT PAR= 500
OLS ESTIMATION
      85 OBSERVATIONS      DEPENDENT VARIABLE = LPRODUCT
...NOTE..SAMPLE RANGE SET TO: 1, 85
SUM OF LOG(SQRT(ABS(WEIGHT))) = -14.973

R-SQUARE = 0.2187      R-SQUARE ADJUSTED = 0.1796
VARIANCE OF THE ESTIMATE-SIGMA**2 = 3.0290
STANDARD ERROR OF THE ESTIMATE-SIGMA = 1.7404
SUM OF SQUARED ERRORS-SSE= 242.32
MEAN OF DEPENDENT VARIABLE = 5.7185
LOG OF THE LIKELIHOOD FUNCTION = -180.107

MODEL SELECTION TESTS - SEE JUDGE ET.AL.(1985, P.242)
AKAIKE (1969) FINAL PREDICTION ERROR- FPE = 3.2072
(FPE ALSO KNOWN AS AMEMIYA PREDICTION CRITERION -PC)
AKAIKE (1973) INFORMATION CRITERION- LOG AIC = 1.1653
SCHWARZ(1978) CRITERION-LOG SC = 1.3089
MODEL SELECTION TESTS - SEE RAMANATHAN(1992,P.167)
CRAVEN-WAHBA(1979) GENERALIZED CROSS VALIDATION(1979) -GCV= 3.2183
HANNAN AND QUINN(1979) CRITERION -HQ= 3.3976
RICE (1984) CRITERION-RICE= 3.2310
SHIBATA (1981) CRITERION-SHIBATA= 3.1862
SCHWARTZ (1978) CRITERION-SC= 3.7023

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AKAIKE (1974) INFORMATION CRITERION-AIC= 3.2068

ANALYSIS OF VARIANCE - FROM MEAN				
	SS	DF	MS	F
REGRESSION	67.832	4.	16.958	5.598
ERROR	242.32	80.	3.0290	P-VALUE
TOTAL	310.15	84.	3.6923	0.001

ANALYSIS OF VARIANCE - FROM ZERO				
	SS	DF	MS	F
REGRESSION	2847.4	5.	569.49	188.010
ERROR	242.32	80.	3.0290	P-VALUE
TOTAL	3089.8	85.	36.350	0.000

VARIABLE ELASTICITY	ESTIMATED	STANDARD	T-RATIO	PARTIAL STANDARDIZED		
NAME	COEFFICIENT	ERROR	80 DF	P-VALUE	CORR. COEFFICIENT	AT
MEANS						
LCAPMO2	0.12388E-01	0.7825E-02	1.583	0.117	0.174	0.1572
0.1087						
LFERTPR1	0.41907	0.1414	2.964	0.004	0.315	0.3009
0.3256						
LSLOED2	-0.18377	0.1104	-1.664	0.100	-0.183	-0.1680
0.1256						
LSOIL1	1.2170	0.5955	2.044	0.044	0.223	0.2025
0.7178						
CONSTANT	-0.15176	2.167	-0.7003E-01	0.944	-0.008	0.0000
0.0265						

|_ols lproduct lcapmo2 lfertpr1 lsloed2 lsoil4/ weight=wgt anova

REQUIRED MEMORY IS PAR= 76 CURRENT PAR= 500

OLS ESTIMATION

85 OBSERVATIONS

DEPENDENT VARIABLE = LPRODUCT

...NOTE...SAMPLE RANGE SET TO: 1, 85

SUM OF LOG(SQRT(ABS(WEIGHT))) = -14.973

R-SQUARE = 0.2312 R-SQUARE ADJUSTED = 0.1927

VARIANCE OF THE ESTIMATE-SIGMA**2 = 2.9806

STANDARD ERROR OF THE ESTIMATE-SIGMA = 1.7264

SUM OF SQUARED ERRORS-SSE= 238.45

MEAN OF DEPENDENT VARIABLE = 5.7185

LOG OF THE LIKELIHOOD FUNCTION = -179.422

MODEL SELECTION TESTS - SEE JUDGE ET.AL.(1985, P.242)

AKAIKE (1969) FINAL PREDICTION ERROR- FPE = 3.1560

(FPE ALSO KNOWN AS AMEMIYA PREDICTION CRITERION -PC)

AKAIKE (1973) INFORMATION CRITERION- LOG AIC = 1.1492

SCHWARZ(1978) CRITERION-LOG SC = 1.2928

MODEL SELECTION TESTS - SEE RAMANATHAN(1992,P.167)

CRAVEN-WAHBA(1979) GENERALIZED CROSS VALIDATION(1979) -GCV= 3.1669

HANNAN AND QUINN(1979) CRITERION -HQ= 3.3433

RICE (1984) CRITERION-RICE= 3.1793

SHIBATA (1981) CRITERION-SHIBATA= 3.1353

SCHWARTZ (1978) CRITERION-SC= 3.6431

AKAIKE (1974) INFORMATION CRITERION-AIC= 3.1555

ANALYSIS OF VARIANCE - FROM MEAN				
	SS	DF	MS	F
REGRESSION	71.704	4.	17.926	6.014
ERROR	238.45	80.	2.9806	P-VALUE
TOTAL	310.15	84.	3.6923	0.000

ANALYSIS OF VARIANCE - FROM ZERO				
	SS	DF	MS	F
REGRESSION	2851.3	5.	570.26	191.323
ERROR	238.45	80.	2.9806	P-VALUE
TOTAL	3089.8	85.	36.350	0.000

VARIABLE ELASTICITY	ESTIMATED	STANDARD	T-RATIO	PARTIAL STANDARDIZED		
NAME	COEFFICIENT	ERROR	80 DF	P-VALUE	CORR. COEFFICIENT	AT
MEANS						
LCAPMO2	0.11690E-01	0.7761E-02	1.506	0.136	0.166	0.1484
0.1026						
LFERTPR1	0.41971	0.1402	2.994	0.004	0.317	0.3014
0.3261						
LSLOED2	-0.16635	0.1097	-1.517	0.133	-0.167	-0.1521
0.1137						
LSOIL4	0.75320	0.3199	2.354	0.021	0.255	0.2318
0.5297						
CONSTANT	0.88817	1.553	0.5718	0.569	0.064	0.0000
0.1553						

|_ols lproduct lcapmo2 lfertpr1 lsloed2 lsoil5/weight=wgt anova

REQUIRED MEMORY IS PAR= 76 CURRENT PAR= 500
 OLS ESTIMATION
 85 OBSERVATIONS DEPENDENT VARIABLE = LPRODUCT
 ...NOTE...SAMPLE RANGE SET TO: 1, 85
 SUM OF LOG(SQRT(ABS(WEIGHT))) = -14.973

R-SQUARE = 0.3487 R-SQUARE ADJUSTED = 0.3162
 VARIANCE OF THE ESTIMATE-SIGMA**2 = 2.5249
 STANDARD ERROR OF THE ESTIMATE-SIGMA = 1.5890
 SUM OF SQUARED ERRORS-SSE= 201.99
 MEAN OF DEPENDENT VARIABLE = 5.7185
 LOG OF THE LIKELIHOOD FUNCTION = -172.369

MODEL SELECTION TESTS - SEE JUDGE ET.AL.(1985, P.242)
 AKAIKE (1969) FINAL PREDICTION ERROR- FPE = 2.6734
 (FPE ALSO KNOWN AS AMEMIYA PREDICTION CRITERION -PC)
 AKAIKE (1973) INFORMATION CRITERION- LOG AIC = 0.98321
 SCHWARZ (1978) CRITERION-LOG SC = 1.1269
 MODEL SELECTION TESTS - SEE RAMANATHAN(1992,P.167)
 CRAVEN-WAHBA(1979) GENERALIZED CROSS VALIDATION(1979) -GCV= 2.6827
 HANNAN AND QUINN(1979) CRITERION -HQ= 2.8321
 RICE (1984) CRITERION-RICE= 2.6932
 SHIBATA (1981) CRITERION-SHIBATA= 2.6559
 SCHWARTZ (1978) CRITERION-SC= 3.0861
 AKAIKE (1974) INFORMATION CRITERION-AIC= 2.6730

ANALYSIS OF VARIANCE - FROM MEAN				
	SS	DF	MS	F
REGRESSION	108.16	4.	27.041	10.710
ERROR	201.99	80.	2.5249	P-VALUE
TOTAL	310.15	84.	3.6923	0.000

ANALYSIS OF VARIANCE - FROM ZERO				
	SS	DF	MS	F
REGRESSION	2887.8	5.	577.56	228.747
ERROR	201.99	80.	2.5249	P-VALUE
TOTAL	3089.8	85.	36.350	0.000

VARIABLE ELASTICITY NAME	ESTIMATED COEFFICIENT	STANDARD ERROR	T-RATIO 80 DF	P-VALUE	PARTIAL CORR. COEFFICIENT	STANDARDIZED AT
MEANS						
LCAPMO2	0.18467E-01	0.7281E-02	2.536	0.013	0.273	0.2344
0.1621						
LFERTPR1	0.35400	0.1301	2.721	0.008	0.291	0.2542
0.2751						
LSLOED2	-0.32824	0.1058	-3.101	0.003	-0.328	-0.3001
0.2243						
LSOIL5	1.6042	0.3502	4.581	0.000	0.456	0.4416
1.5317						
CONSTANT	-4.2575	1.958	-2.175	0.033	-0.236	0.0000
0.7445						
_test						
_test lsloed2=0						
_test lcapmo2=0						
_test lfertpr1=0						
_test lsoil5=0						
_end						
F STATISTIC = 10.709952 WITH 4 AND 80 D.F. P-VALUE= 0.00000						
WALD CHI-SQUARE STATISTIC = 42.839809 WITH 4 D.F. P-VALUE= 0.00000						
UPPER BOUND ON P-VALUE BY CHEBYCHEV INEQUALITY = 0.09337						
_test lsloed2						
TEST VALUE = -0.32824 STD. ERROR OF TEST VALUE 0.10584						
T STATISTIC = -3.1013728 WITH 80 D.F. P-VALUE= 0.00266						
F STATISTIC = 9.6185135 WITH 1 AND 80 D.F. P-VALUE= 0.00266						
WALD CHI-SQUARE STATISTIC = 9.6185135 WITH 1 D.F. P-VALUE= 0.00193						
UPPER BOUND ON P-VALUE BY CHEBYCHEV INEQUALITY = 0.10397						
_test lcapmo2						
TEST VALUE = 0.18467E-01 STD. ERROR OF TEST VALUE 0.72811E-02						
T STATISTIC = 2.5362337 WITH 80 D.F. P-VALUE= 0.01315						
F STATISTIC = 6.4324816 WITH 1 AND 80 D.F. P-VALUE= 0.01315						
WALD CHI-SQUARE STATISTIC = 6.4324816 WITH 1 D.F. P-VALUE= 0.01121						
UPPER BOUND ON P-VALUE BY CHEBYCHEV INEQUALITY = 0.15546						
_test lfertpr1						
TEST VALUE = 0.35400 STD. ERROR OF TEST VALUE 0.13011						
T STATISTIC = 2.7207267 WITH 80 D.F. P-VALUE= 0.00799						
F STATISTIC = 7.4023536 WITH 1 AND 80 D.F. P-VALUE= 0.00799						
WALD CHI-SQUARE STATISTIC = 7.4023536 WITH 1 D.F. P-VALUE= 0.00651						
UPPER BOUND ON P-VALUE BY CHEBYCHEV INEQUALITY = 0.13509						
_test lsoil5						
TEST VALUE = 1.6042 STD. ERROR OF TEST VALUE 0.35019						
T STATISTIC = 4.5808625 WITH 80 D.F. P-VALUE= 0.00002						
F STATISTIC = 20.984301 WITH 1 AND 80 D.F. P-VALUE= 0.00002						
WALD CHI-SQUARE STATISTIC = 20.984301 WITH 1 D.F. P-VALUE= 0.00000						
UPPER BOUND ON P-VALUE BY CHEBYCHEV INEQUALITY = 0.04765						
_ols lproduct lcapmo2 lfertpr1 lsloed2 lsoil5/weight=wgt anova						
REQUIRED MEMORY IS PAR= 76 CURRENT PAR= 500						
OLS ESTIMATION						
85 OBSERVATIONS DEPENDENT VARIABLE = LPRODUCT						
...NOTE...SAMPLE RANGE SET TO: 1, 85						
SUM OF LOG(SQRT(ABS(WEIGHT))) = -14.973						
R-SQUARE = 0.3487 R-SQUARE ADJUSTED = 0.3162						
VARIANCE OF THE ESTIMATE-SIGMA**2 = 2.5249						
STANDARD ERROR OF THE ESTIMATE-SIGMA = 1.5890						
SUM OF SQUARED ERRORS-SSE= 201.99						
MEAN OF DEPENDENT VARIABLE = 5.7185						
LOG OF THE LIKELIHOOD FUNCTION = -172.369						
MODEL SELECTION TESTS - SEE JUDGE ET.AL.(1985, P.242)						
AKAIKE (1969) FINAL PREDICTION ERROR- FPE = 2.6734						
(FPE ALSO KNOWN AS AMEMIYA PREDICTION CRITERION -PC)						
AKAIKE (1973) INFORMATION CRITERION- LOG AIC = 0.98321						

SCHWARZ(1978) CRITERION-LOG SC = 1.1269
 MODEL SELECTION TESTS - SEE RAMANATHAN(1992,P.167)
 CRAVEN-WAHBA(1979) GENERALIZED CROSS VALIDATION(1979) -GCV= 2.6827
 HANNAN AND QUINN(1979) CRITERION -HQ= 2.8321
 RICE (1984) CRITERION-RICE= 2.6932
 SHIBATA (1981) CRITERION-SHIBATA= 2.6559
 SCHWARTZ (1978) CRITERION-SC= 3.0861
 AKAIKE (1974) INFORMATION CRITERION-AIC= 2.6730

	SS	DF	MS	F
REGRESSION	108.16	4.	27.041	10.710
ERROR	201.99	80.	2.5249	P-VALUE
TOTAL	310.15	84.	3.6923	0.000

	SS	DF	MS	F
REGRESSION	2887.8	5.	577.56	228.747
ERROR	201.99	80.	2.5249	P-VALUE
TOTAL	3089.8	85.	36.350	0.000

VARIABLE ELASTICITY	ESTIMATED	STANDARD	T-RATIO	PARTIAL STANDARDIZED
NAME	COEFFICIENT	ERROR	80 DF	P-VALUE CORR. COEFFICIENT AT
MEANS				
LCAPMO2	0.18467E-01	0.7281E-02	2.536	0.013 0.273 0.2344
0.1621				
LFERTPR1	0.35400	0.1301	2.721	0.008 0.291 0.2542
0.2751				
LSLOED2	-0.32824	0.1058	-3.101	0.003-0.328 -0.3001 -
0.2243				
LSOIL5	1.6042	0.3502	4.581	0.000 0.456 0.4416
1.5317				
CONSTANT	-4.2575	1.958	-2.175	0.033-0.236 0.0000 -
0.7445				

|_confid lcapmo2 lfertpr1 lsloed2 lsoil5
 USING 95% AND 90% CONFIDENCE INTERVALS

CONFIDENCE INTERVALS BASED ON T-DISTRIBUTION WITH 80 D.F.

- T CRITICAL VALUES = 1.980 AND 1.658

NAME	LOWER 2.5%	LOWER 5%	COEFFICIENT	UPPER 5%	UPPER 2.5%	STD.
ERROR						
LCAPMO2	0.4050E-02	0.6395E-02	0.18467E-01	0.3054E-01	0.3288E-01	0.007
LFERTPR1	0.9638E-01	0.1383	0.35400	0.5697	0.6116	0.130
LSLOED2	-0.5378	-0.5037	-0.32824	-0.1528	-0.1187	0.106
LSOIL5	0.9108	1.024	1.6042	2.185	2.298	0.350

```
|_gen1 L1=log(2899)**2
|_gen1 L2=log(8.3)**2
|_gen1 MPP0=1.6042*exp(-4.2575)*exp(0.018467*L1)*(148.5**0.35400)*exp(-
0.32824*L2)*(284**(1.6042-1))
|_gen1 MPP1=0.9108*exp(-8.13434)*exp(0.00405*L1)*(148.5**0.09638)*exp(-
0.53780*L2)*(284**(0.91080-1))
|_gen1 MPP2=2.29800*exp(-0.38066)*exp(0.03288*L1)*(148.5**0.61160)*exp(-
0.11870*L2)*(284**(2.29800-1))
|_gen1 MPP3=1.0240*exp(-7.50386)*exp(0.006395*L1)*(148.5**0.13830)*exp(-
0.50370*L2)*(284**(1.02400-1))
|_gen1 MPP4=2.1850*exp(-1.01114)*exp(0.03054*L1)*(148.5**0.56970)*exp(-
0.15280*L2)*(284**(2.18500-1))
|_**estimated MPP of soil quality (SOIL5) per hectare
|_print MPP0
MPP0
3.010398
|_**lower bounds at 95% confidence interval
|_print MPP1
MPP1
```

0.3040617E-04

```

|_**upper bounds at 95% confidence interval
|_print MPP2
    MPP2
    242845.8
|_**lower bounds at 90% confidence interval
|_print MPP3
    MPP3
    0.2029818E-03
|_**upper bounds at 90% confidence interval
|_print MPP4
    MPP4
    38948.05
|_smpl 1 85
|_sort int heduc product lproduct lcapmo2 lfertpr1 lsloed2 lsoil5 soil5
DATA HAS BEEN SORTED BY VARIABLE INT
|_sort heduc product lproduct lcapmo2 lfertpr1 lsloed2 lsoil5 soil5
DATA HAS BEEN SORTED BY VARIABLE HEDUC
|_smpl 1 35
|_stat heduc product soil5


| NAME    | N  | MEAN    | ST. DEV | VARIANCE    | MINIMUM     | MAXIMUM |
|---------|----|---------|---------|-------------|-------------|---------|
| HEDUC   | 35 | 0.65783 | 1.0552  | 1.1134      | 0.10000E-02 | 3.0000  |
| PRODUCT | 35 | 848.76  | 828.35  | 0.68616E+06 | 1.0718      | 2693.1  |
| SOIL5   | 35 | 316.23  | 176.81  | 31261.      | 96.549      | 787.16  |


|_?ols lproduct lcapmo2 lfertpr1 lsloed2 lsoil5
|_gen1 sse1=$sse
..NOTE..CURRENT VALUE OF $SSE = 105.44
|_smpl 51 85
|_stat heduc product soil5


| NAME    | N  | MEAN   | ST. DEV | VARIANCE    | MINIMUM | MAXIMUM |
|---------|----|--------|---------|-------------|---------|---------|
| HEDUC   | 35 | 8.4286 | 2.5928  | 6.7227      | 6.0000  | 15.000  |
| PRODUCT | 35 | 835.18 | 832.74  | 0.69345E+06 | 0.71065 | 2739.2  |
| SOIL5   | 35 | 245.88 | 158.43  | 25102.      | 82.586  | 727.24  |


|_?ols lproduct lcapmo2 lfertpr1 lsloed2 lsoil5
|_gen1 sse2=$sse
..NOTE..CURRENT VALUE OF $SSE = 150.60
|_gen1 GQheduc=sse2/sse1
|_print GQheduc
    GQHEDUC
    1.428287
|_smpl 1 85
|_sort int macho product lproduct lcapmo2 lfertpr1 lsloed2 lsoil5 soil1 soil4
soil5
DATA HAS BEEN SORTED BY VARIABLE INT
|_sort macho product lproduct lcapmo2 lfertpr1 lsloed2 lsoil5 soil1 soil4
soil5
DATA HAS BEEN SORTED BY VARIABLE MACHO
|_smpl 1 25
|_stat macho product soil1 soil4 soil5


| NAME    | N  | MEAN        | ST. DEV | VARIANCE     | MINIMUM     | MAXIMUM     |
|---------|----|-------------|---------|--------------|-------------|-------------|
| MACHO   | 25 | 0.10000E-02 | 0.00000 | -0.10663E-20 | 0.10000E-02 | 0.10000E-02 |
| PRODUCT | 25 | 921.74      | 899.17  | 0.80851E+06  | 0.71065     | 2543.7      |
| SOIL1   | 25 | 28.520      | 7.4505  | 55.510       | 17.000      | 48.000      |
| SOIL4   | 25 | 55.211      | 30.793  | 948.22       | 23.393      | 141.93      |
| SOIL5   | 25 | 280.50      | 151.33  | 22901.       | 96.549      | 727.24      |


|_?ols lproduct lcapmo2 lfertpr1 lsloed2 lsoil5/weight=wtg
|_gen1 sse1=$sse
..NOTE..CURRENT VALUE OF $SSE = 89.408
|_smpl 61 85
|_stat macho product soil1 soil4 soil5


| NAME    | N  | MEAN   | ST. DEV | VARIANCE    | MINIMUM | MAXIMUM |
|---------|----|--------|---------|-------------|---------|---------|
| MACHO   | 25 | 4.7600 | 7.5348  | 56.773      | 1.0000  | 29.000  |
| PRODUCT | 25 | 1005.5 | 979.74  | 0.95989E+06 | 1.0072  | 3790.9  |
| SOIL1   | 25 | 34.440 | 10.583  | 112.01      | 18.000  | 60.000  |
| SOIL4   | 25 | 74.421 | 41.192  | 1696.8      | 28.475  | 160.97  |


```

```

SOIL5      25   316.55      192.56      37080.      89.963      837.41
|_?ols lproduct lcapmo2 lfertpr1 lsloed2 lsoil5/weight=wgt
|_gen1 sse2=$sse
..NOTE..CURRENT VALUE OF $SSE =   63.375
|_gen1 GQmacho=sse1/sse2
|_print GQmacho
      GQMACHO
      1.410782
|_smpl 1 85
|_stat product capmox fertpr1 sloedit soil5
NAME      N      MEAN      ST. DEV      VARIANCE      MINIMUM      MAXIMUM
PRODUCT   85      848.26      865.47      0.74904E+06      0.71065      3790.9
CAPMOX    85      2899.0      2233.2      0.49873E+07      1.0000      7170.0
FERTPR1   85      148.50      129.13      16674.      0.99669      714.84
SLOEDIT   85      8.3000      3.6032      12.983      1.0000      18.000
SOIL5     85      284.18      175.40      30763.      82.586      837.41
|_stat lproduct lcapmo lfertpr1 lsloed lsoil5
NAME      N      MEAN      ST. DEV      VARIANCE      MINIMUM      MAXIMUM
LPRODUCT  85      5.5506      2.2703      5.1542      0.53688      8.2406
LCAPMO     85      7.0113      2.0773      4.3153      0.00000      8.8777
LFERTPR1   85      4.3355      1.6316      2.6622      -0.33145E-02      6.5721
LSLOED     85      2.0013      0.53377     0.28491      0.00000      2.8904
LSOIL5     85      5.4883      0.56077     0.31447      4.4138      6.7303
|_stat lproduct lcapmo2 lfertpr1 lsloed2 lsoil5
NAME      N      MEAN      ST. DEV      VARIANCE      MINIMUM      MAXIMUM
LPRODUCT  85      5.5506      2.2703      5.1542      0.53688      8.2406
LCAPMO2    85      53.423      23.967      574.44      0.00000      78.813
LFERTPR1   85      4.3355      1.6316      2.6622      -0.33145E-02      6.5721
LSLOED2    85      4.2867      1.8180      3.3053      0.00000      8.3542
LSOIL5     85      5.4883      0.56077     0.31447      4.4138      6.7303
|_genr lcapmo20=log(capmo2)
|_genr lsloed20=log(sloed2)

|_ols lproduct lcapmo20 lfertpr1 lsloed20 lsoil5/weight=wgt

REQUIRED MEMORY IS PAR=   78 CURRENT PAR=   500
OLS ESTIMATION
      85 OBSERVATIONS      DEPENDENT VARIABLE = LPRODUCT
..NOTE..SAMPLE RANGE SET TO:   1,   85
SUM OF LOG(SQRT(ABS(WEIGHT))) = -14.973

R-SQUARE =   0.1943      R-SQUARE ADJUSTED =   0.1540
VARIANCE OF THE ESTIMATE-SIGMA**2 =   4.3728
STANDARD ERROR OF THE ESTIMATE-SIGMA =   2.0911
SUM OF SQUARED ERRORS-SSE=   349.82
MEAN OF DEPENDENT VARIABLE =   5.4660
LOG OF THE LIKELIHOOD FUNCTION = -195.710

MODEL SELECTION TESTS - SEE JUDGE ET.AL.(1985, P.242)
AKAIKE (1969) FINAL PREDICTION ERROR- FPE =   4.6300
(FPE ALSO KNOWN AS AMEMIYA PREDICTION CRITERION -PC)
AKAIKE (1973) INFORMATION CRITERION- LOG AIC =   1.5324
SCHWARZ(1978) CRITERION-LOG SC =   1.6761
MODEL SELECTION TESTS - SEE RAMANATHAN(1992,P.167)
CRAVEN-WAHBA(1979) GENERALIZED CROSS VALIDATION(1979) -GCV=   4.6460
HANNAN AND QUINN(1979) CRITERION -HQ=   4.9048
RICE (1984) CRITERION-RICE=   4.6643
SHIBATA (1981) CRITERION-SHIBATA=   4.5997
SCHWARTZ (1978) CRITERION-SC=   5.3447
AKAIKE (1974) INFORMATION CRITERION-AIC=   4.6293

      ANALYSIS OF VARIANCE - FROM MEAN
      SS      DF      MS      F
REGRESSION      84.339      4.      21.085      4.822
ERROR           349.82      80.      4.3728      P-VALUE
TOTAL           434.16      84.      5.1686      0.002

```

ANALYSIS OF VARIANCE - FROM ZERO

	SS	DF	MS	F
REGRESSION	2623.9	5.	524.77	120.009
ERROR	349.82	80.	4.3728	P-VALUE
TOTAL	2973.7	85.	34.984	0.000

VARIABLE	ESTIMATED	STANDARD	T-RATIO	PARTIAL STANDARDIZED		
ELASTICITY						
NAME	COEFFICIENT	ERROR	80 DF	P-VALUE	CORR. COEFFICIENT	AT
MEANS						
LCAPMO20	0.90366E-01	0.6358E-01	1.421	0.159	0.157	0.1468
0.2366						
LFERTPR1	0.34891	0.1351	2.583	0.012	0.277	0.2623
0.2682						
LSLOED20	-0.16901	0.2424	-0.6972	0.488	-0.078	-
0.1259						
LSOIL5	1.4272	0.4366	3.269	0.002	0.343	0.3374
1.4279						
CONSTANT	-4.4102	3.073	-1.435	0.155	-0.158	0.0000 -
0.8068						
_stop						
□						

APPENDIX FIVE

VARIABLE SPECIFICATIONS AND CALCULATIONS

The purpose of this chapter is to report on the manner in which certain variables used in chapter four were specified and calculated. The six variables that were applied in the analysis, in generalized terms, were: productivity (production value per hectare), labour, farm capital stock, fertilizer application, field slope, and soil quality. Detailed specifications and calculations for these variables are as follows:

1. **Output prices:** Production value is the estimated value of production (1993 prices) of field output. Production value was calculated as follows:

maize @ M 0.6206 / kg
 sorghum @ M 0.5756 / kg
 wheat @ M 0.8414 / kg
 potatoes @ M 0.70 / kg
 peas @ M 2.2473 / kg
 beans @ M 2.00 / kg
 pumpkins @ M 0.33 / kg
 watermelons @ M 0.33 / kg

N.B. The pricing on potatoes, pumpkins, and watermelons was set by the author and may not reflect official prices. Given the relatively small proportion these crops occupy in the total output value, any problems with pricing will have minimal impact on the outcome of the study.

2. From each household, a field was selected for analysis (see field analysis below). The area of the field was calculated by measured paces and geometric estimations undertaken by the author. Due to the fact that most of the fields were irregularly shaped, and given the number of fields which were estimated (for area), more technical estimation techniques were not employed.

3. Calculation of three labour supply variables were undertaken through spread sheet manipulations. Perhaps the easiest way to express how three labour variables (specified in chapter four) were determined is by providing an example of how one labour variable was determined within a spreadsheet calculation below. All statistics from each household observation were collated and summarized on an individual spreadsheet.

LABOUR APPLICATION- REAL/PRODUCTIVE MEASURE									
64	1	1	1	1	1	1	0.7	1	0.7
70	1	0	0.5	1	0	1	1	1	0
38	1	1	1	1	1	1	1	1	1
16	1	1	1	1	1	0.5	1	1	0.5
14	1	1	1	1	1	0.5	1	1	0.5
0	0	0	1	1	1	1	0.7	0	0
AGE(> 8)	> 80	PRIME	> 65	8-12YRS	SICK	STUDENT	GENDER	PEOPLE	
TOTAL									2.7

The above table is used to calculate a productive labour statistic for each household (**RLAB**). The first column extracts household members under 8 years of age. The second column extracts members over 80 years of age. The third column establishes members in productive years (between 12 and 65). The fourth column establishes which members are not between 8 and 12; those that are are score 0.7 rather than a full or one unit of labour. The fifth column extracts terminally sick family members from the sample. The next column scores students as one-half a unit of labour. The sixth column is somewhat contentious and requires a brief qualification. Women are scored 0.7 of a full unit of labour owing primarily to the household chores that can take away from their ability to perform in the fields. This exact form of scoring women in agricultural labour was included in (name of study forthcoming**). The impact of this gender-scoring

procedure is unlikely to change the results from the empirical study in chapter four. The penultimate column is used in ensuring that blank rows are not scored. The final column sums the rows whose values are summed below and printed beside "TOTAL."

FAMILY LABOUR						
1	1	1	1	1	1	1
1	0	1	0	1	1	0
1	1	1	1	1	1	1
1	1	1	1	1	1	1
1	1	1	1	1	1	1
0	1	1	1	0	1	0
ACTIVE	SICK	WORKER	NOT-S-W	FARM	W-N-S-W	AGE
TOTAL						4

In calculating family labour (**FLAB**), the following tabulating procedures are followed. Column one ensures that blanks are not tabulated. Column two ensures that the terminally sick are not included in the FLAB calculation. Column three and four ensure that the family member is not working or residing off-farm. Column five ensures that the family member is engaged in farm work. Column six is used to ensure appropriate summation of values while column six is used to remove infants less than eight years old from the summation.

A final labour variable (**PLAB**) simply comprises the total number of on- and off-farm family members. Determining the farm capital (stock) variable involved determining the farm machinery owned by the household, and then calculating a value.

APPENDIX SIX

A BRIEF REVIEW OF THE MACHOBANE FARM SYSTEM

The Machobane farm system is essentially a farming practise that involves rotations of crops throughout the year, intercropping and the incorporation of wood ash and manure into cropland to enhance soil fertility over time. The system was developed by Dr. James Jacob Machobane over some 30 years of private research on his own farmland in western Lesotho. Machobane later opened a college of agriculture promoting the system because of his concern for the problems of food security experienced by many villagers in Lesotho.

The system calls for crops such as potatoes (planted with moderate amounts of fertilizer), wheat, maize, sorghum, beans, pumpkins, and watermelons. If the system is initiated in the colder months, a potato crop is likely to be planted first. A mixture of two parts dried cow dung to one part wood ash is blended and placed in a small hole where individual potato seeds are placed. One tablespoon of fertilizer is then added to the mixture (after this point, no more fertilizer is applied). As the winter begins to pass, a row, possibly of maize, sorghum and pumpkin, is sown between the rows of ripening potatoes. Again, at this stage of planting, more manure and wood ash are incorporated into the soil to continue building its fertility. While it is not necessary for this paper to go into great detail about the Machobane system of farming, the rationale behind the system should be pointed out.

The Machobane Farm System, a system which has won Dr. Machobane international acclaim and attention from organizations such as the Food and Agricultural

Organization (FAO), provides a means of generating food production in drought conditions and in years of heavy rains due primarily to the diversity and soil-building qualities inherent in the system. The system can be described as bio- and labour intensive and suitable to the culture, climate, and soils of Lesotho. In 1993 there were over 600 households practising the system in the lowlands and foothills of Lesotho.

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